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Frugal Leafy Green Shredding & Washing Machines

Seth Brown

Guillermo Escobar

Shane Murphy

Leslie Valenzuela

Ben Voelz

SANTA CLARA UNIVERSITY

Department of Mechanical Engineering
Department of General Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Seth Brown, Guillermo Escobar, Shane Murphy,
Leslie Valenzuela, Ben Voelz

ENTITLED

FRUGAL LEAFY GREEN SHREDDING & WASHING MACHINES

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Jessica Kuczenski, Advisor and Department Chair, General Engineering — Date

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Godfrey Mungal, Advisor, Mechanical Engineering — Date

06/08/22

Hohyun Lee, Department Chair, Mechanical Engineering — Date

FRUGAL LEAFY GREEN SHREDDING & WASHING MACHINES

By

Seth Brown, Guillermo Escobar, Shane Murphy,
Leslie Valenzuela, Ben Voelz

SENIOR DESIGN PROJECT REPORT

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ABSTRACT

The goal of this project is to create specialized frugal appliances to assist women in rural Cameroon by reducing the amount of time it takes to prepare food. Specifically, the project focuses on two tasks: slicing eru leaves and washing bitter leaves. After researching the market and collecting information from women in South Cameroon, two appliances were designed: an eru leaf shredder and a bitter leaf washer. The shredder is a manual shredding device that uses a rotating blade and shaft subsystem to slice leaves, reducing labor time by 62% and increasing safety with features such as a hopper and an ergonomic crank handle. The washer is a manual washing device that features a rotating agitator that reduces the amount of time taken to wash bitter leaves by 50% and reduces the amount of water usage by 75%. Both devices are held in a portable housing unit that allows them to be easily moved and stored.

ACKNOWLEDGMENTS

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Chapter 1: Introduction

Our team has partnered with the Victoria Relief Foundation (VRF), a nonprofit based out of South Cameroon. The VRF aims to sustainably address fast growing humanitarian challenges. Their mission is to rekindle hope, provide relief and build resilience for the most vulnerable victims of violent conflict in Sub-Saharan Africa, with a specific focus on the ongoing conflict in Southern Cameroon. We were connected to them through the Frugal Innovation Hub, a program on campus that works hand-in-hand with nonprofit organizations, on tech projects aimed to support organizational efforts for communities in need.

1.1 Background: Geopolitical and Economic Context

Due to political conflict in Southern Cameroon, a Civil War erupted in 2016, displacing over 1.2 million citizens. Many have watched their villages burn down and have had to endure violent attacks, causing them to flee. Some citizens fled to neighboring countries, and others (about 600,000 inhabitants) were pushed to the rural forest areas of South Cameroon, where there is a lack of infrastructure and limited access to low cost, safe and effective fuel sources to aid them in the processing and cooking of meals [1].

The forced displacement has consequently pushed many families to find other means through which they can provide reliable sources of aliment and income. For those that have moved to rural areas this means relying on nutrition from the bush.

The bush has two native leafy greens which are a staple food source in South Cameroon: the eru leaf (Figure 1) and bitter leaf (Figure 2) [2].

Figure 1. Eru leaf [3].

Figure 2. Harvesting of bitter leaves [4].

The women of South Cameroon forage eru leaf and bitter leaf daily from the bush. Their day usually begins around 6 A.M, when they take a several mile trek before arriving at the farms from which they harvest produce. After about an 8-10 hour work day, they then make their way home to begin preparing dinner for their families.

These leaves are usually boiled and made into stews or served as a side dish. They are also commonly used for their medicinal properties, as they have been known to help lower blood pressure, help with sore throats, and act as a purgative. On account of their nutritional and medicinal value, these leaves are commonly used in every household, leading many women to sell buckets of them at local markets.

Although we were unable to know the exact price range and earning from selling these leaves, we were able to obtain general income information to try and understand the financial implications the leaves have on Cameroonian families. The average yearly income in South Cameroon is around $1520 USD [5]. Monthly, they are earning $126 USD, which means they have a weekly income of about $32 USD.

1.2 Problem Statement and Project Objective

Eru leaf and Bitter leaf both require a large amount of processing before consumption. As a result, women spend hours every day preparing these foods with basic cooking equipment. This is a big issue because not only are they a main source of nutrition, but they also serve an important part of their income generation. Women in South Cameroon are in need of a more efficient and effective way of processing these leafy greens so that they can spend their time in a more engaging manner, reduce ergonomic injuries that come from their current processes, and decrease the amount of resources the processes require. Our senior design team will focus on developing two low cost manual kitchen appliances for women in South Cameroon to decrease the processing time of leafy greens and increase safety, ultimately improving the quality of life for women in rural areas of Cameroon.

1.3 Current Methods

The eru leaf is sliced using a conventional kitchen knife. The user will typically have a large bowl of eru leaf, a small wood plank used as a cutting board, and another bowl below the cutting board to collect the slices. A handful of leaves are taken from the bowl and wrapped together before cutting small slices from the bundle with a knife. The two step process outlined below will usually take anywhere from 1 to 2 hours depending on the amount of Eru leaves that they are making. For a family of four this is about 16 oz of leaves.

1) Bundling: *A handful of leaves are wrapped and rolled into a bundle together.*
2) Slicing: *A knife is used to thinly slice the bundles.*

Figure 3. Sliced and bundled eru leaf [6].

The bitter leaf must be washed to remove some or all of the bitterness depending on preference and dish. This is generally done in a three step process:

1) Soaking: *the leaves are placed in a bowl of water and soaked.*
2) Scrubbing*: the leaves are scrubbed and washed by hand.*
3) Limestone (optional step): *Limestone rocks are used to scrub the leaves and remove bitterness.*

Figure 4. Traditional washing of bitter leaves [7].

This process is repeated multiple times, replacing the dirty water with fresh water multiple times to achieve the desired level of bitterness for each dish. For a family of four, an average of 16 oz. of leaves are used and washed with 1 gallon of water and takes about an hour.

1.4 Literature Review

This literature review focuses on current solutions for food washing and shredding that the team can draw inspiration from, as well as analysis of these products, and methods to go about having to produce a more frugal product.

1.4.1 Method - Frugal Product Design

Frugal product development is a more humanitarian approach to engineering that involves creating practical, low-cost, and durable products and processes. Currently, there is a lack of knowledge on Frugal Innovation amongst engineers in academic settings. There have been several reviews written that encompasses almost all our current knowledge of frugal innovations [8]. Although these are well written and comprehensive, they do not focus on how to actually do the frugal innovation process. The author suggests it is extremely useful to analyze the features and specifics of the frugal innovation process to then be able to go through the process yourself.

Many shredder designs were made to fulfill a need specifically in locations that have easy and affordable access to electricity (see 1.4.2.). In the future, the design should take on a frugal approach to access lower income and rural areas that can only operate mechanically, or off of solar power.

1.4.2. Existing Shredders

The need for efficient, effective, and economic shredders is still prevalent in many industries. In particular, there is an increasing need for widely available and affordable plastic shredder machines, the ones on the market are difficult to attain and extremely expensive. A portable and low-cost plastic shredder was created to fill this gap in the market. The unique value proposition of this product is its ability to process the plastic waste right then and there in the industrial facilities that are producing the plastic waste. It's extremely cost effective because it reduces the cost of additional processing and transportation to outside processing plants [9].

Another example of an existing shredder is in agricultural production. Agricultural production outputs large amounts of agricultural waste that can pose an environmental hazard. The Coconut Leaves Shredder [9] was built to reduce the size of agricultural waste (in this case coconut leaves) by turning it into nourishing fertilizer.

Before designing the shredder, extensive market research was conducted and comparable solutions were benchmarked, taking into account advantages and disadvantages of the designs. Table 1 describes the current designs advantages and disadvantages.

Table 1. Advantages and disadvantages of current models.

Current models	Advantage	Disadvantage
Pedal operated shredder machine	Uses kinetic energy Best for processes that occur intermittently	Efficiency quite less per hour Not user friendly Human power required Complicated design. Requires more time to cut
Hand operated chaff cutter machine	Can cut all types of greens and fodder Eco friendly Easy to maintain	Low cutting rate Heaviest weight Requires more power to cut the coconut leaves No safety Transportation is very difficult.
Tractor PTO Model	Outputs a stick of shredded leaf that can be stored	Complicated design Expensive Requires Tractor Wear and tear of blades occurs frequently

1.4.2 Discussion

The need for efficient, effective, and economic shredders is prevalent in many industries. There are several improvements to be made to both of the shredder designs, and several factors to consider when redesigning them. Currently, shredders that function properly are expensive and inefficient. The design of shredder that follows frugal design principles is still needed in the market. More specifically, a manual shredder is missing from the market as there have been multiple iterations of electrical ones [10]. Additionally, some things to consider when designing our product would be the addition of a hopper or sieve, a hand vs. pedal mechanism, and the portability of the design. The size and shape of the sieve opening were explored, but the way that the recyclates were inserted was not described. In the future, it would be beneficial to explore the position of each recyclate as it enters the shredder and how that affects the efficiency.

1.5 Patent Research and Benchmarking

Before proceeding to creating our own concept sketches, existing patents were researched to get a better understanding about how current solutions work. Once patents were found, the team went through each to identify useful aspects and areas for improvement. This information would be useful for our own concept generation so we could incorporate pieces of existing solutions and come up with ways to improve areas where they underperform.

Metrics were created based on the identified customer needs to quantify the statements. For example, mobility was an important need that was identified for all of the appliances. Therefore size and weight were chosen metrics to define mobility. Using these metrics, existing solutions were benchmarked to understand how they perform and to help identify areas for improvement. As the appliances being designed in this project are very specific, existing solutions were not found to tackle the exact problem statement, but perform similar tasks.

1.5.1 Shredder

For the eru leaf shredder, two existing solutions were found: a french fry cutter and the Slap Chop. The french fry cutter works by inserting a potato then squeezing it through a mesh to get slices. A similar approach could be used for the eru leaf. The Slap Chop is a sort of food processor that uses a spring loaded pump on top.

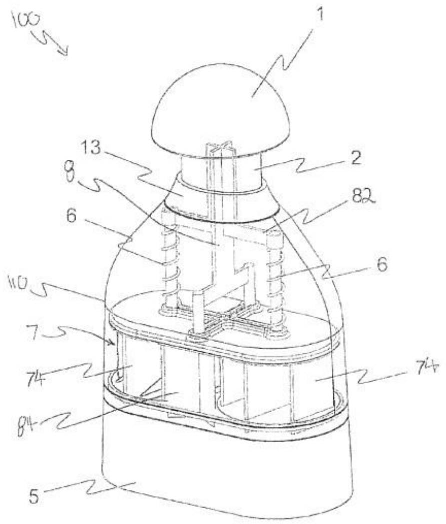


Figure 5. Food chopper [11].

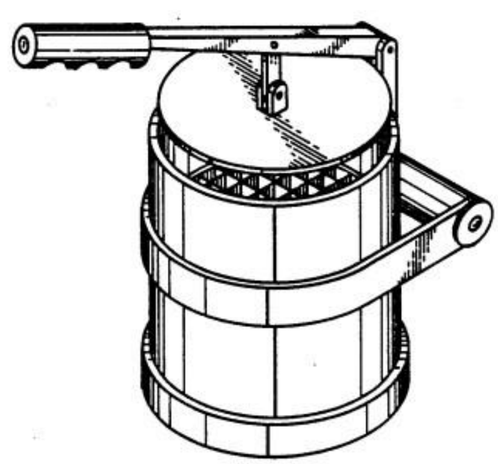


Figure 6. French fry cutter [12].

Link to full patent can be found in Appendix A.

1.5.2 Washer

For the bitter leaf washer, two existing solutions were analyzed: a food processor and a salad spinner. Both of these appliances involve a container with blades that rotate the contents. The food processor uses electricity to spin the blades while the salad spinner uses a simple pump method.

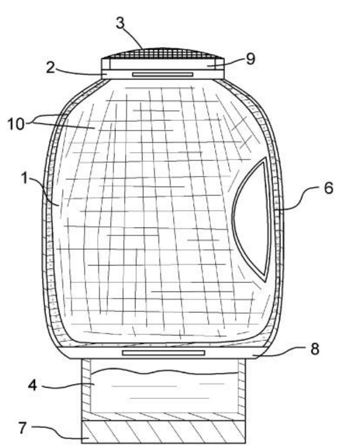


Figure 7. Portable fruit and vegetable washer [13].

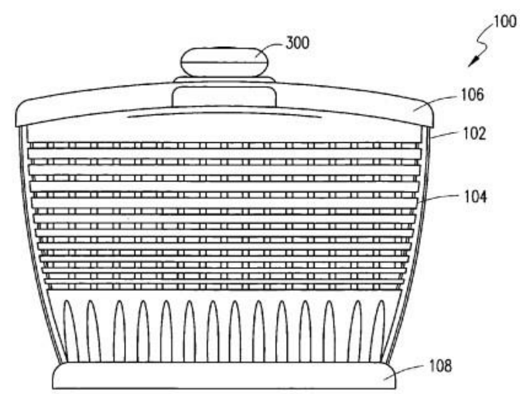


Figure 8. Salad spinner with improved drive assembly [14].

Link to full patent can be found in Appendix A.

1.6 Market Survey

Due to the nature of working with a partner in a foreign country, we knew communication and collecting user feedback would be a struggle. We didn't want to constrain our user feedback because of distance, so we sent out user surveys to locals that were from South Cameroon. A representative from VRF also forwarded our survey to personal contacts and friends he knew. This survey helped us collect quantitative data to understand how many users were facing similar problems and pain points. Example survey questions are provided below in Table 2.

Table 2. Example questions from market survey.

Southern Cameroons Food Technology User Studies Survey
1. Gender a. Female b. Male c. Prefer not to answer d. Other
2. Where do you currently live? a. Urban city in Southern Cameroons b. Rural area in Southern Cameroons c. Other
3. What is the current tool you use to accomplish the task?
4. How do you use the tool to accomplish the task at hand?
5. What is the most difficult part about accomplishing this task?

The full set of questions is available in Appendix B.

On the other hand, an individual interview was also necessary for us to be able to empathize with the users and see the problem from their perspective. We conducted an individual survey with a local woman who was born and raised in South Cameroon. This interview better allowed us to understand the process from beginning to end and fill in any missing key information that we had previously overlooked or thought to be of little importance. The full list of interview questions are available in Appendix B.

Chapter 2: Project Specifications

This section covers the identified project specifications from customer needs as well as the project management.

2.1 Customer Needs

After reviewing the survey results sent to several communities in Southern Cameroon, we came up with several tables (refer to Appendix B) to dictate the solution specifications based on customer needs for each machine. We itemized the results of the survey and rated them from one to five to see the importance of each need.

Table 3. Eru leaf shredder customer needs.

Need Number	Part	Need	**Importance** 5 = high 1 = low
1	The appliance	is cheap.	5
2	The appliance	reduces the amount of time needed to slice the leaf.	5
3	The appliance	reduces the force and concentration needed to slice the leaf.	5
4	The appliance	is rugged enough to go through several wash cycles.	4
5	The appliance	is small so it doesn't take up too much space in the kitchen.	4
6	The appliance	is light enough to be able to be moved around the kitchen.	4
7	The appliance	is easy to build (so people in South Cameroon can recreate it).	3
8	The appliance	is able to slice a large amount of leaves at one time.	4
9	The appliance	is easy to clean	4
10	The appliance	is safe to use.	5
11	The appliance	is easy to use without the need of a lot of instruction	3
12	The appliance	uses resources efficiently.	4
13	The blade	is sharp enough to slice eru.	5
14	The blade	is durable.	4
15	The blades	have adjustable spacing.	4
16	The shell	is durable and strong enough for travel.	4

Table 4. Bitter leaf washer customer needs

Need Number	Part	Need	Importance 5 = high 1 = low
1	The appliance	is cheap.	5
2	The appliance	reduces the amount of time needed to wash the leaf.	5
3	The appliance	reduces the force and focus needed to wash the leaf.	5
4	The appliance	is rugged enough to go through several wash cycles.	5
5	The appliance	is small so it doesn't take up too much space in the kitchen.	4
6	The appliance	is light enough to be able to be moved around the kitchen.	4
7	The appliance	is easy to build (so people in South Cameroon can recreate it).	3
8	The appliance	uses water and other resources efficiently.	4
9	The appliance	is easy to clean	4
10	The appliance	is water resistant	5
11	Chemical reactant	is basic to reduce acidity.	5

2.1.1 Key Findings

Women in South Cameroon are in need of a more efficient and effective way of processing these leafy greens so that they can spend their time in a more engaging manner, reduce ergonomic injuries that come from their current processes, and decrease the amount of resources the processes require.

We were able to pinpoint three main areas of concern:

1. Time:
    - Eru leaf: can take anywhere between 60 to 90 minutes to completely slice a typical amount collected in a day, which is usually enough to feed a family of four.
    - Bitter leaves: can take about two full hours to process enough leaves for a family of 6-8.
2. Injuries
    - Cuts to the upper extremities are common
    - The exposed blade of a knife is a safety hazard to children who regularly help their mothers with the processing and preparing of food.

- Ergonomic injuries are prevalent amongst the women who process these leaves. Their traditional methods require them to sit/squat and position their shoulders ahead of their hips, leaving them in an uncomfortable position for hours. This posture leads to lower back pain and joint issues over a prolonged period of time.

3. Price Point
    - Given the nature of working with a frugal tool, low cost is a priority. Weekly, their wages are roughly $35 USD. When asked what a reasonable price point was, they responded that they would be willing to pay for a tool that is priced around $10-$15.

2.1.2 Product Specifications

From this list, we were able to discern our product specifications. The main goals for the appliances are given below and the full list of product specifications is provided in Appendix B.

1. Time - Efficient and Effect:
    - The eru leaf slicer must process an equal or larger volume or leaves for a family of four in 30 minutes.
    - The bitter leaf washer must process an equal or larger volume of leaves for a family of 4 in 30 minutes
2. Safety
    - There will be no exposed blades.
    - Minimal exertion will be required due to the mechanical nature but will remain minimal.
3. Price Point
    - Both products will cost less than $15 to manufacture.

Our senior design team will focus on developing two low cost manual kitchen appliances for women in South Cameroon to decrease the processing time of leafy greens and increase safety, ultimately improving the quality of life for women in rural areas of Cameroon.

2.2 User Scenario

A user scenario was created to outline a potential scenario where the appliances would be used. This exercise allowed us to visualize the performance of the products and validate aspects of the design that could have been overlooked. The user scenario shown in Figure 9 depicts a fictional instance which shows how our product would be used and the impact it would have. Our target customers are women living in rural areas of South Cameroon who rely on the bush to feed their families and generate income. The scenario begins with our user collecting leafy greens. Our target consumer collects leaves for 8-10 hours daily throughout the week so that she is able to gather enough to sell at the markets on Saturdays. At the end of the week, they arrive home late at night and spend hours processing the leaves so that they are market ready. The following day, one of our users is seen at the market processing leaving on the spot for customers. The user explains the effectiveness and efficiency of the washer and shredder for being able to sell freshly cut and washed leaves. The user also explains how to connect to the VRF and the impact the product has made on their lives.

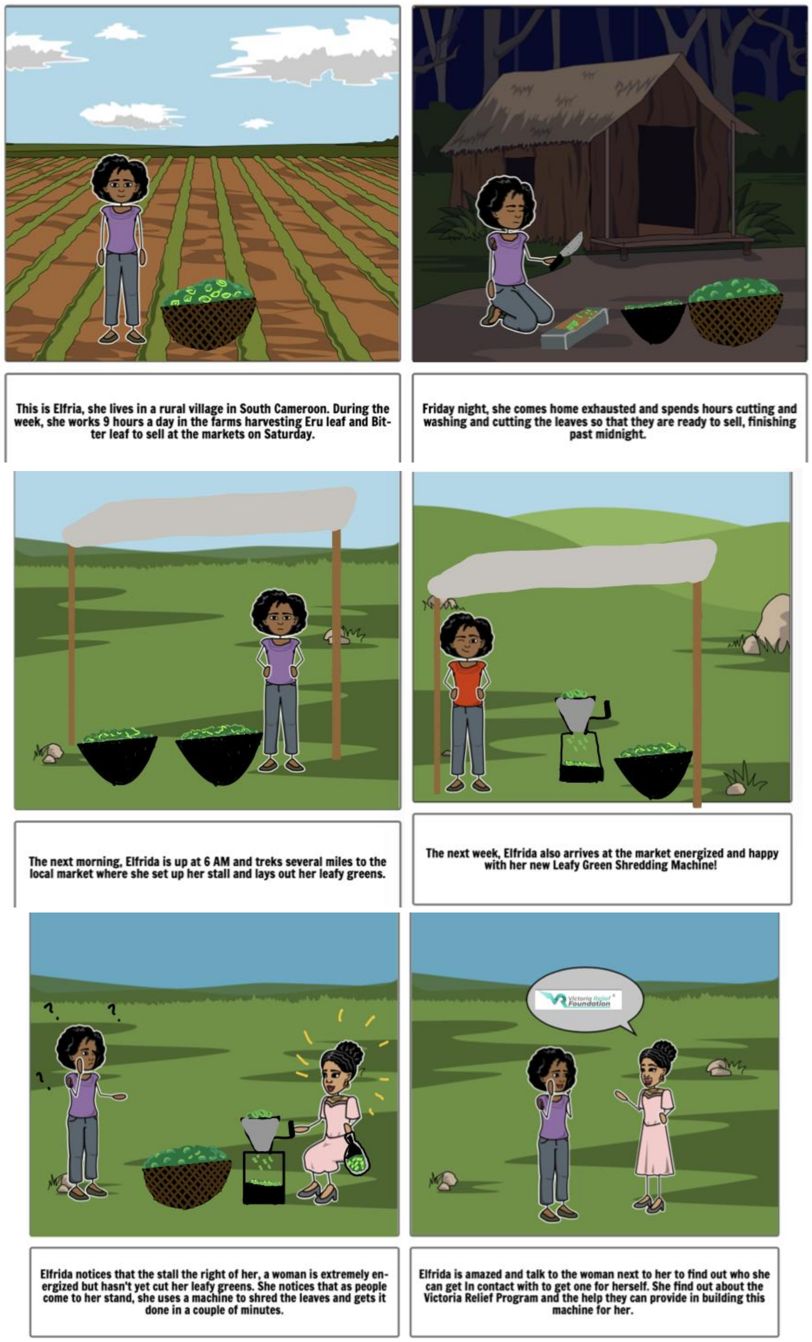


Figure 9. User scenario.

2.3 Project Management

The following section will explain the process and decisions the team made to envision our products. This timeline allowed benchmarking in order to ensure proper progress and direction for the research and development of the products through challenges, risk mitigation and team management.

2.3.1 Budget

We received $2500 from the Santa Clara University School of Engineering for our project. The budget was split into three major categories: building, testing, and personal protective equipment (PPE). The building section consists of the materials we would need in order to build the prototype devices. The testing section includes any items purchased for benchmarking or reverse engineering purposes. Finally, the PPE section contains the equipment purchased for use in testing to prevent injury. We were able to stay well within our given budget. A full bill of materials is included in Appendix C.

2.3.2 Safety and Risk Mitigations

Our product will require the use of gears and rotating parts for it to function correctly. Thus, the risk of rotating parts, gears and centrifugal forces catching on loose items, hair, clothing and jewelry needs to be considered. This risk will be mitigated by practicing proper safety procedures in the maker lab while prototyping. The final product will have a cover for the gears and will come with safety instructions in order to allow for users to maneuver the product as intended.

Our product will also deal with sharp objects. Sharp blades and other components have potential to cause minor and even severe injuries if not properly used and contained. In order to address this we will be using cut resistant gloves, wearing eye protection, and following all safety precautions in the maker lab.

Another consideration is the use of heavy materials. Making sure that we are using proper lifting techniques and working together so that no one is injured by falling, dropping or breaking something.

One of the bigger risks in our design and modeling process is metal fabrication. The use of welding, cutting, drilling and more can create a dangerous situation if not properly mitigated. In order to stay as safe as possible, we will be sure to use safety goggles, wear gloves, use a welding mask when necessary and follow the guidelines from our training.

Appendix D contains a visual guide to demonstrate our risk assessment.

2.3.3 *Timeline*

Throughout the school year, our project followed, approximately, the following agenda for each quarter:

Fall Quarter:

- Brainstorm project ideas
- Market research
- Concept deliberation and finalization
- Securing funding
- Defining team/project goals
- CAD modeling

Winter Quarter

- CAD Simulations
- Prototyping
- Testing and Analysis
- Begin thesis

Spring Quarter

- Update CAD with final details
- Manufacture final product
- Construct and present Senior Design Conference Presentation
- Complete thesis

2.3.4 *Design Process*

During the fall quarter, the team began the design process by first attempting to understand the social and cultural contexts of our target market, women from rural South Cameroon regions. From there, design options were explored while we researched the market for patents, products, and designs that could assist in our own product development process. We established goals and more concise ideas to proceed in conceptualization.

After analyzing each concept and evaluating feasibility, we were able to narrow down and finalize ideas. We discovered that washing machines, salad spinners, fruit and vegetable washers, food cutters, and paper shredders allowed us to enhance our designs as these devices all provided insight on the fluid dynamics and cutting processes seen in the project's initial concepts.

From there, we were able to use Solidworks to model and run simulations. Our analysis led to further exploration of the concepts we had finalized in the beginning of the winter quarter, marking the start of the prototyping process.

Prototyping led to the creation of the concepts we had been constructing and evaluating using computers. Many changes were made as a result of the testing process. We made improvements based on the analysis of these testing procedures.

By the beginning of the spring quarter, we used our knowledge gathered from experimentation to manufacture the final product. Small adjustments translated the most updated prototypes into finalized CAD models and manufactured devices. We ran final tests to ensure the completed assemblies of the bitter leaf washer and eru leaf slicer worked as intended in the manner expected, which they did.

Chapter 3: System Level Analysis

At the system level, we explain what both of our appliances need to do, process and methods for how we can achieve this, and analyze systems-level results.This chapter will go more in depth about what each machine is meant to do and give an overview of the subsystems that are in each machine.

3.1 Functional Analysis

For the system analysis we needed to accomplish the customer needs determined by a survey we made for the people of Southern Cameroon. We put most of our focus on creating a machine that would be affordable for the users to buy, easy to build and maintain, and reduce the time that it currently takes to complete the tasks using traditional methods. We had some similar priorities for both appliances, but also each had its own specifications and objectives as described below.

Eru Leaf shredder:
1. Able to shred leaves to a width of half a centimeter
2. Reduce the time it takes to cut by fifty percent
3. Reduce the stress produced in the hand by using a knife
4. Cost less than fifteen dollars to manufacture
5. Appliance can be built easily without experience
6. Easy maintenance and clean up

Bitter Leaf Washer
1. Cut washing time by fifty percent
2. Reduce the amount of water used by fifty percent
3. Cost less than ten dollars
4. Appliance can be built easily without experience
5. Easy maintenance and clean up

3.2 Overview of Subsystems

After understanding what our customer needs were we came up with designs for each appliance. The original concept sketches and selection tables can be found in Appendix E and F respectively. The final design for each appliance and its main subsystems are briefly covered in this section and will be covered in more detail in subsequent chapters.

3.3.1 Shredder

Our shredder has a total of five subsystems where one of them is also shared with the bitter leaf washing machine. The subsystems start by cranking the handle manually, and having the gears rotate the shafts where the blades and spacers are. After having a continuous rotation the hopper will feed in the leaves into the blades to come out on the other side thinly sliced.

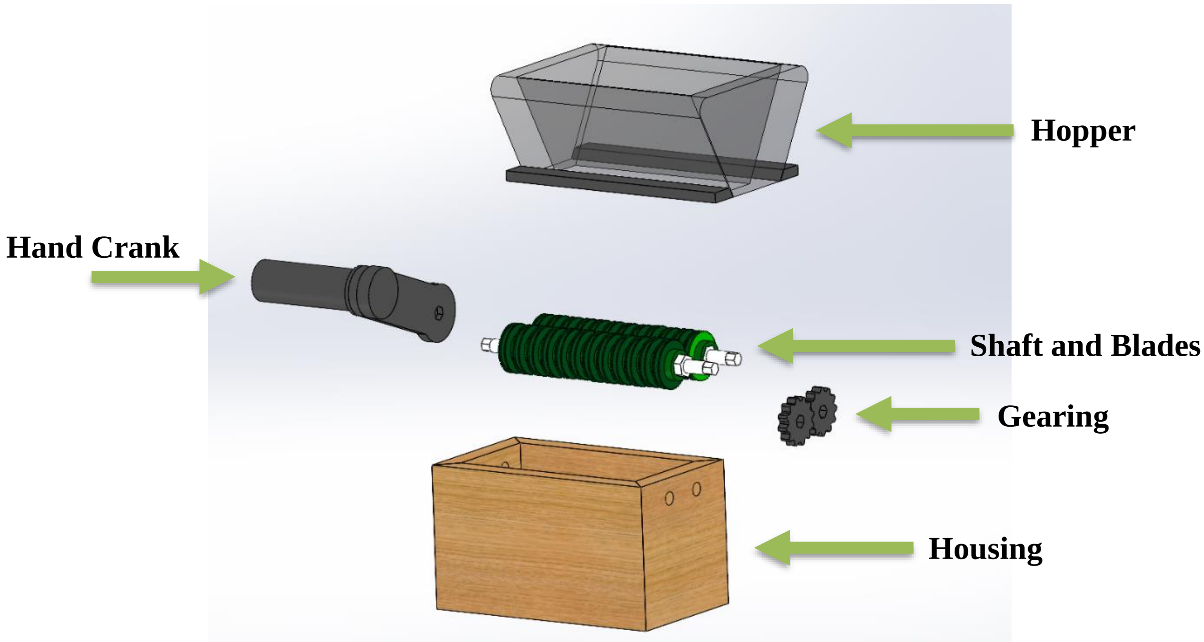


Figure 10. Eru leaf shredder exploded view.

3.2.2 Washer

Our washer design has a total of four main subsystems with one of them being the handle. The substems being the housing component to keep the water and everything inside, the mount that is glued to the bottom of the housing. The agitator that connects with the mount since these two pieces go together, and finally the handle which is the one that makes the agitator create the water movement.

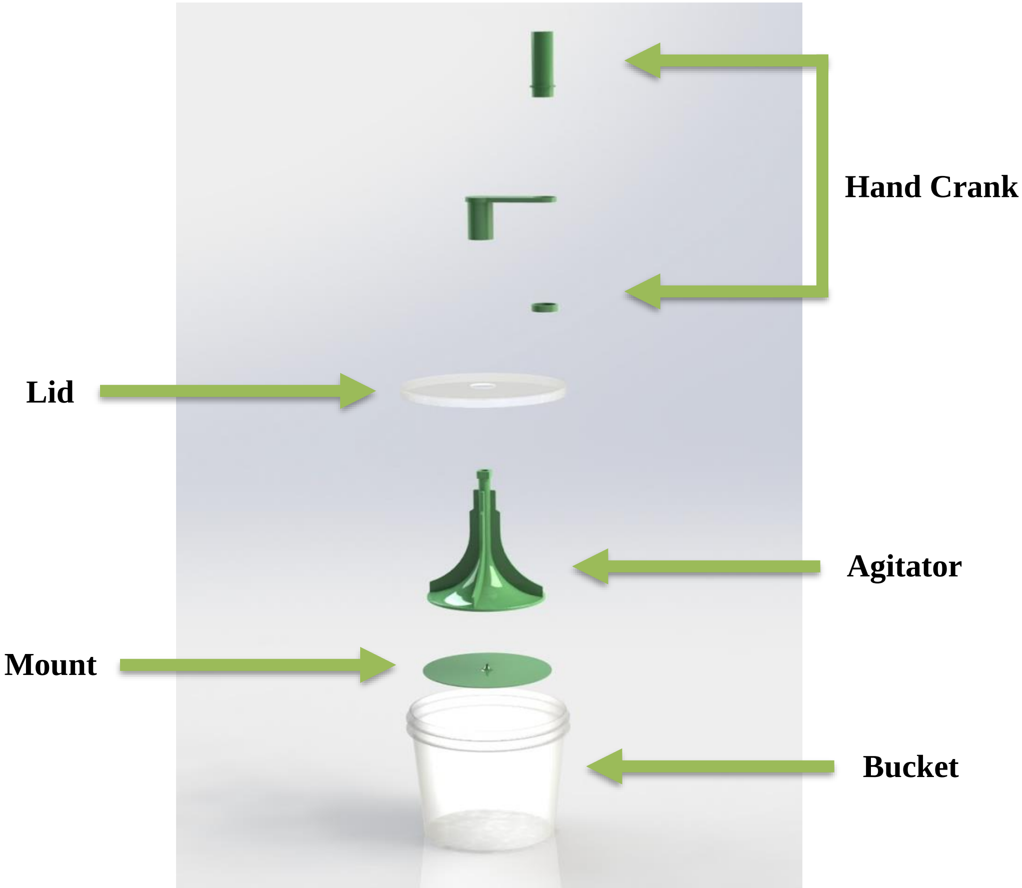


Figure 11. Bitter leaf washer exploded view.

In this image you can see how the four main subsystems are connected with each other and how they work together.

3.4 Handle

The handle is the main interface between the user and each appliance. The Eru Leaf Shredder and Bitter Leaf Washer both require a rotational input for operation. Using a hand crank was chosen as a simple and robust method to directly apply the action for the appliances.

3.4.1 Background

The rotational input mechanism must provide adequate leverage and functionality while also having a simple design. The Eru Leaf Shredder operates by the rotation of two shafts with a series of blades. The motion of these blades draws in and cuts the leaves. The Bitter Leaf Washer operates by the rotation of the agitator, a component that causes a mixing fluid flow that, in turn, works to soak and scrub out the bitterness in the Bitter Leaf.

3.4.2 User Needs

Based on the chosen designs for the appliances, the conclusion was made that they would require a rotational input. The needs of our target market were considered early on in the design process for the input mechanism. Research and surveys led to the conclusion that the overall design of the appliances must be simple and robust so that it can easily and cost effectively be manufactured and not require a high degree of maintenance. It was also clear that the mechanism had to be straightforward to use and allow the user to complete the task with minimal effort.

3.4.3 Handle Design Options

As part of a frugal system, it was required that the handle be cost effective and easy to manufacture. To meet these goals, it was ultimately decided that the part would be 3D printed and that a similar design would be used for both appliances. This allows parts to be shared between the two designs and reduces complexity.

Based on research of existing solutions for applying a rotational input, three options were identified: a pull cord, push button, and hand crank.

The pull cord is a mechanism that applies rotational movement when the user pulls the string. This design is seen in various products such as generators, lawn mowers, and some salad spinners. This design would require a string wrapped around a shaft so that when the user pulls back on it, the shaft will rotate. Although this is an effective method, we decided not to pursue it as the complexity of such a system would require a higher price point and likely the need for more frequent maintenance.

The push button is a mechanism that applies rotational movement when the user pushes down on a button. This design is seen in products like salad spinners to rotate the inner basket at a high speed. The push button design uses a screw which, when forced down, applies rotational motion. The mechanism is used in a salad spinner which contains a basket with relatively light contents and little friction. Our applications would both encounter much more friction and thus require a higher input force and more frequent inputs to keep the apparatus spinning. It was concluded that such a system would not be feasible for our design despite its relatively low complexity.

The simplest and most direct form of rotational input, a hand crank, was selected for both appliances. A hand crank can easily be made from PLA using 3D printing and its simplicity meant that it would be cost effective and require little maintenance. Alternative materials and methods of manufacturing the handle were considered such as laser cutting acrylic, wood, or buying an existing mechanism, however none were nearly as cost effective.

3.4.4 Design 1

The initial hand crank design was based on existing solutions such as a bicycle crank. Design iterations followed from testing, alternating its size, thickness, and features until the mechanism was well suited for the application of both appliances.

The first hand crank design was entirely tubular, following example designs seen for existing products. For the Eru Leaf Shredder, the crank would slot into the end of one of the blade shafts and could be rotated about the horizontal axes to apply motion. For the Bitter Leaf Washer, the crank would slot into the top of the agitator and rotate about the vertical axis. The designs that this was based upon were all made from metal and could be formed in such a manner. For our chosen manufacturing process of 3D printing however, this would not be efficient. Printing this design would require three different parts, the three cylinders that make up the design, to be printed separately and then assembled. This complexity led to a design change and the next iteration of the hand crank design.

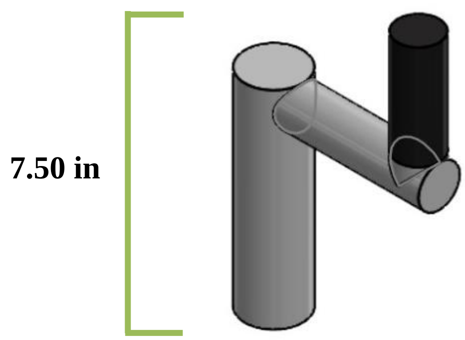


Figure 12. First hand crank design.

3.4.5 Design 2

The second hand crank design featured a flat 'arm' that allowed for easier printing. The crank could now be printed as just two parts with the handle printed separately then slotted and glued into the arm. In testing it was noted that the crank was difficult to spin as the handle was stationary and would slide in the user's hand as they rotated the assembly. Additionally, the handle was too small in both thickness and height.

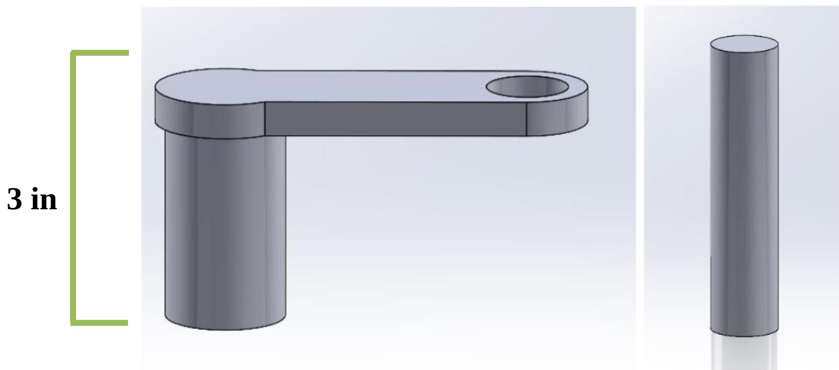


Figure 13. Second hand crank design.

3.4.6 Design 3

The third and final iteration of the hand crank improved upon the previous design to minimize the amount of material used and make the part more user friendly. Material was saved by decreasing the thickness of the arm and minimizing all dimensions to create a more compact form factor. Additionally the shaft that connects the appliance and the arm was shortened. To make the crank easier to use, the handle was made longer to better match the width of a hand and was altered so that it could spin freely. To allow the handle to rotate freely, the hole in the crank arm was extended all the way through to allow the handle to drop through. A lip was then added to the handle to stop it falling through and a small 'cap' was created to attach to the bottom of the handle to secure it within the overall assembly.

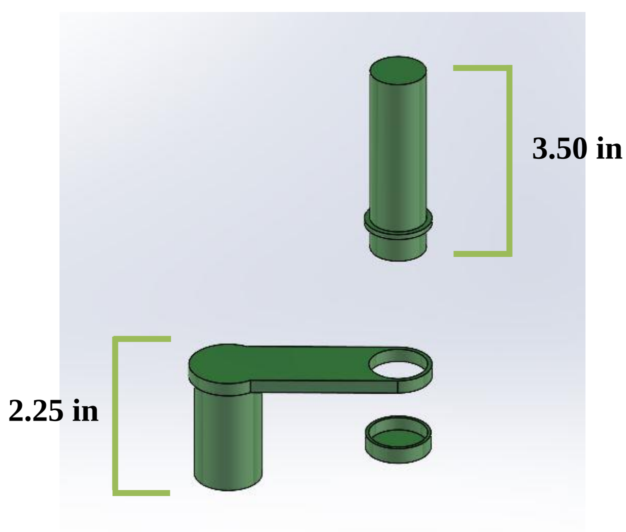


Figure 14. Final hand crank design.

Chapter 4: Shredder

In this chapter we will go more in depth into the shredder machine subsystems. We are going to go into detail about the different design iterations, and how we came up with the final design. Our goal was to ensure that the blades were effective in slicing the eru leaf and allowed users to save time yet cut the same as traditional methods so we did not not compromise the South Cameroon customary dishes. Dimensioned drawings for each part are included in Appendix G and an assembly manual is provided in Appendix H.

4.1 Shaft

This section discusses the design of the blades and shafts used in the eru leaf shredder design. Both went through numerous iterations in both shape and size as a result of testing.

4.1.1 Background

The blade and shaft subsystems are the main components to our appliance. Without the shaft and the blades, our appliance would not be able to accomplish its main function, to shred Eru leaves. The shaft and blade are supposed to flow effortlessly inside the housing component and without much effort to be able to cut the leaves.

4.1.2 Shaft Design

Our inspiration for the shaft came when we opened a hand-cranked paper shredder and the shafts inside of it had a hexagonal shaft holding the blades and spacers. This was easier to do than our original idea of having our shaft with an indentation and blades and spacers with a tooth to come together.

The hexagonal shape design of the shaft helped with the organization of the blades and fixing them in place so they would not rotate. It also helped reduce the assembling time as each blade could be inserted along with the necessary spacers quickly and correctly aligned.

The two shafts need to be different lengths. The first one needs to be six and a half inches to fit inside the housing, go through the housing and connect with one gear outside of the housing. The second shaft needs to connect with the handle so it must be 7 inches to be able to connect with both the handle and the gear.

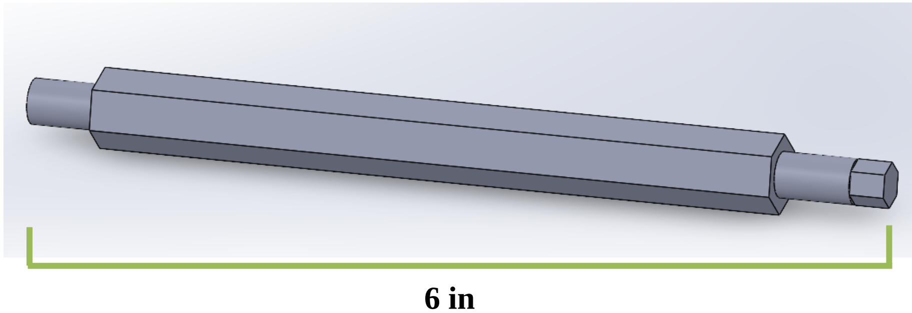


Figure 15. Hexagonal shaft design.

The image above is our final design for our non-handle shaft. As seen, we have the hexagonal part where the blades and spacers fit, but also, you have the hexagonal tip where the gears would connect.

4.2 Blades

The blades were the subsystem we changed the most from our design. We went through a total of 3 different major design changes with a few little adjustments in between them. The small adjustments came on the sense of spacers, organization of blades and spacers and thickness of center of blades to create the separation

4.2.1 Three Pronged Blade

For the first design of the blades that we came up with was a three pronged blade with a hexagonal center.

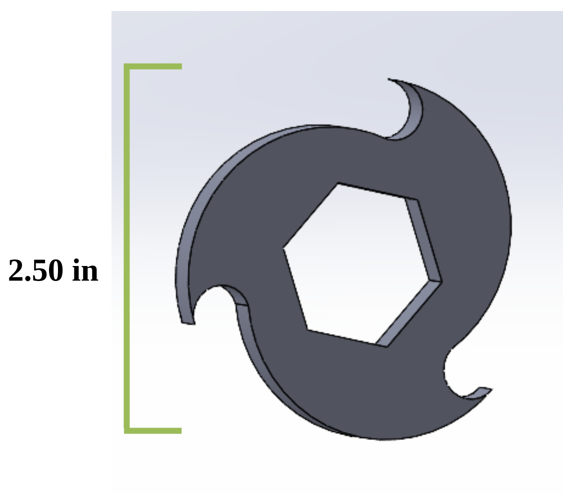


Figure 16. First design iteration of the blade.

The main issues with this first design came with the thickness of the blade, and the fact that it was only using three teeth.

For the first main issue, when doing the testing the blade was too heavy and thick to be able to cut a leaf in even thin pieces since the blade was almost as thick as what we wanted the piece of leaf. The second main issue being with that since it only had three prongs, it wasn't giving any consistency throughout the leaf so it just pierced the lead instead of cutting it through. Although this first design was filled with flaws from the blade to the testing. It was a good first solid step towards understanding what we had to do with the blade and what we had to change.

4.2.2 Large Blade with Small Teeth

For our second design iteration we copied the style of the paper shredder blade by adding several more teeth but we kept the same dimension as the design before because we wanted to test how the amount of teeth affected the cut on the leaf. We also changed the thickness of the blade. Because the previous thickness was thicker than the average cut that we wanted.

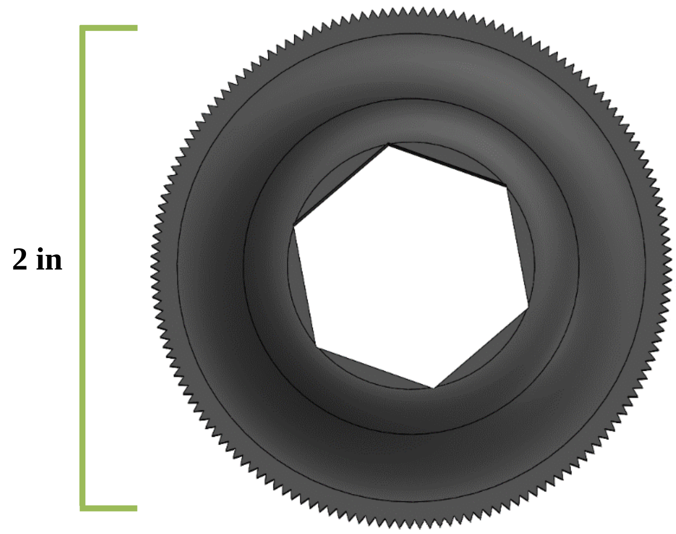


Figure 17. Second design iteration of the blade.

As seen in the above picture, we added a lot more teeth and we also reduced the thickness as mentioned before. To adapt to the change of thickness we added a chamfer to the center of the blade to be able to be the right distance including the spacers. Adding the chamfer, with spacers, helped for the design of the blade to be in between teeth.

4.2.3 Small Blade with Small Teeth

For our third and final design we noticed that the size of the second design was too big in the final machine to carry around and to use properly without stress on the user. So we decided to reduce the size of the whole machine and the blades and spacer by half so we reduced the blade from a two inch diameter to a one inch diameter to have a smaller machine.

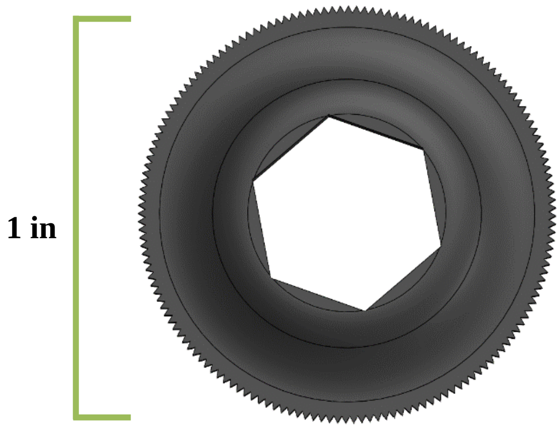


Figure 18. Third design iteration of the blade.

When reducing the diameter of the blade we kept the same thickness since it was the one that made all the blades and spacers fit perfectly in between the blades.

4.2.4 Spacing of Blades

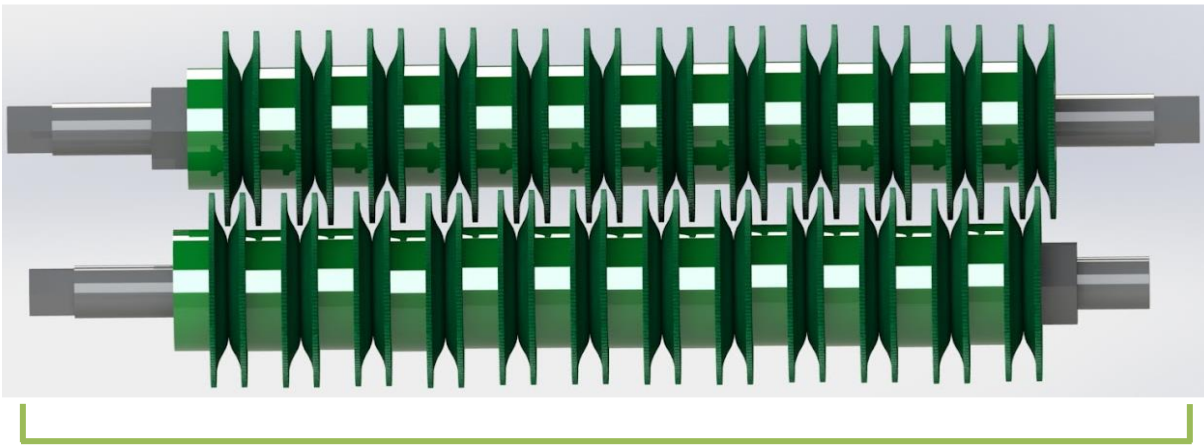
Our first prototype demonstrated the importance of spacing the blades properly to avoid friction and cut the eru leaf properly. Firstly, to address the overlapping problem in prototype 1, we introduced spacers into our product assembly.

Figure 19. Closeup on blade spacing.

In order to achieve the desired thickness, the spacing between each blade varied over many trials in order to obtain slices of roughly 0.5 centimeters width. Ultimately to acquire the desired assembly and spacing, we made each blade and offset spacer 0.2 inches thick.

4.2.5 Prototypes and final design

For our final blade and shaft design we concluded with a one inch diameter blade and with a rough displacement of 0.5 between the teeth of each blade.



6.75 in

Figure 20. Final blade and spacer assembly.

4.2.6 Conclusion

The final design of the blades and shafts reduced the weight by half and made the construction of the housing and manufacturing time faster and easier. Another important factor to consider is that by cutting the size by half we also added force to the blades that were acting from the gear, because there was a lot less material to move and balance.

4.3 Gearing

This section discusses the gearing component of the leaf shredder. The information presented includes the background regarding the design process and gear design options as well as the size, material, gear ratio, and wear and tear upon the finalized product.

4.3.1 Background

It is imperative that the two axles of the shredder move in opposite directions at the same rate. Gearing is the simplest solution to the objective of this design. Since the hand crank is connected to one of the axles of the device, using gears allows for a connection of both axles, thus providing rotation to the axle not connected directly to the hand crank.

4.3.2 Design Options

Although there are many types of gears that accomplish the goals of this aspect of the design, a spur gear design is most in line with what the team wanted to create. Since simplicity is one of the greatest concerns regarding the leaf shredder, a basic two spur gearing system is used. In addition, the gears and axles were made hexagonal so that they could stay assembled and stable throughout the shredding process.

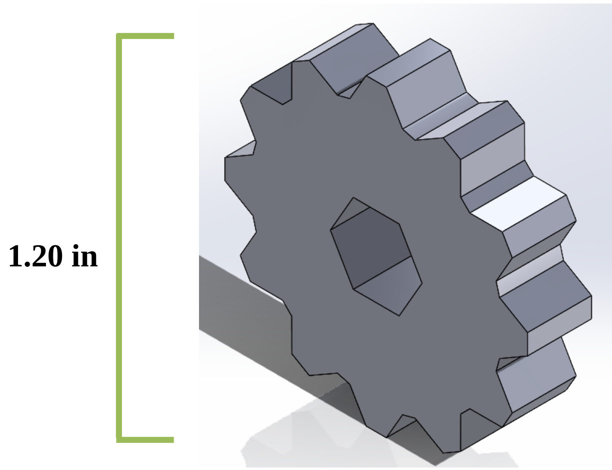


Figure 21. Single hexagonal bore gear design.

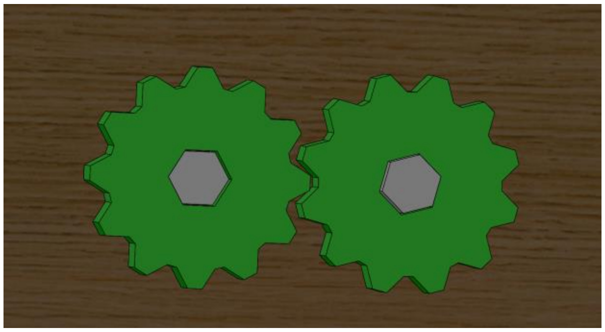


Figure 22. Gear system design.

4.3.3 Size

As shown in Figure 23, the gear has an inner hexagonal bore with side lengths of 0.18 inches and height of 0.31 inches. The gear has a root radius of 0.49 inches and a face width of 0.25 inches. There are 12 teeth with a height of 0.11 inches each.

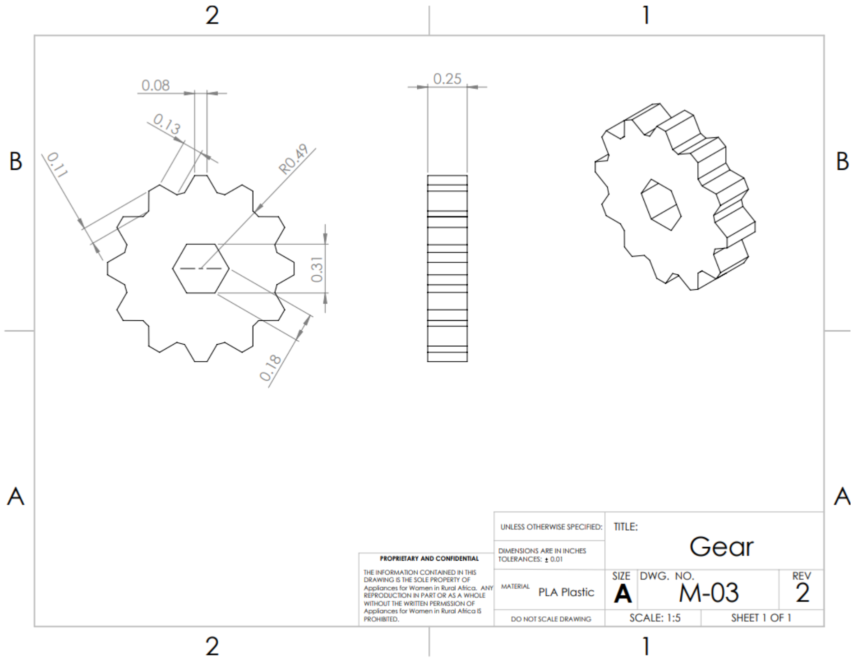


Figure 23. Gear dimensions (see Appendix G, Figure G17).

4.3.4 Material

All the parts for this device besides the housing component are made using a 3D printer. The material chosen for this appliance is food safe PLA plastic, which was determined to be the safest choice due to its high melting point of 180 degrees celsius and lack of toxins that may be released. Since PLA is a porous material, bacterial buildup is an issue after repeated use; because of this, a food safe silicone sealant is being used to coat the PLA parts, including the gears. Doing so creates a smooth surface to mitigate bacteria buildup.

4.3.5 Gear Ratio

The gear ratio used is 1:1 since mechanical advantage was not needed for this device. After testing, it was found that the hand crank provides enough mechanical advantage to the point where turning the axles requires minimal effort.

4.3.6 Wear and Tear

Considering the gears are located on the outside of the housing for the shredder, the gears are exposed to the surrounding environment. Because of this, they will likely undergo more wear and tear, meaning replacement of the gears would most likely occur before the rest of the device's structure, excluding the blades.

Figure 24. Final gear design.

4.4 Housing

In this section we will go in depth about the housing component of our first appliance, the leaf shredder. We will talk about the background in why we chose the designs, the different design options we had and iterations, and finish with the material choice that we decided at the end.

4.4.1 Background

After deciding that we would do a paper-shredder style machine for cutting the leaves we needed to come up with an idea to house the blades, the gears and the hopper in the same simple housing. Due to knowing that the users using the machine might be moving a lot or using the equipment on the go we needed to create something that accomplished all of their needs. We needed to choose a material that was lightweight and resistant to bumps and drops. We also needed a design that covered all of the pain points that the gears, blades, or shafts may cause on the user. We also needed to create the top part of the housing to have a hopper so it could feed the leaves into the blades without having any risk of injury.

4.4.2 Design 1

For our very first housing design as seen in the picture below. We have a three part housing design, which was divided into the leaf storage, the blade and gear housing, and the hopper. This first design gave us an idea on what we wanted concerning safety and storage but was overly complex due to hidden walls inside the housing. The other problem was the design of the hopper. While it was an initial idea, the hopper had to be feeding directly into the mouth of where the blades were cutting so we could avoid wasting time and feeding the leaves one by one.

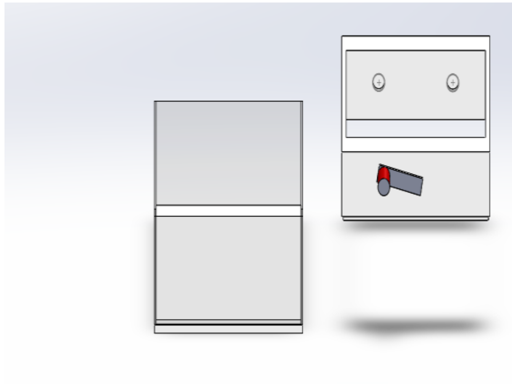


Figure 25. First design iteration of the eru leaf shredder housing and catch basin.

As seen in the figure below, the housing contained holes for the shafts and a closed compartment for the gears but, as mentioned before, we found this design to be difficult to produce and put together. One of our requirements was to be easy to assemble so this design was not adequate.

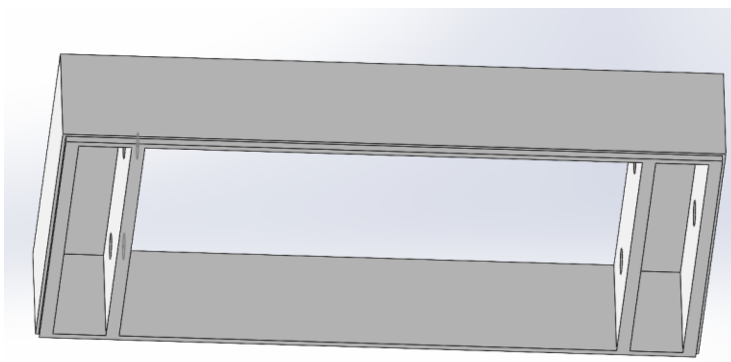


Figure 26. Top component of the eru leaf shredder housing.

4.4.3 Design 2

For our second design iteration of the whole shredder and its housing, we made the housing component without a bottom so the shredded leaves would fall into a separate bucket.. When we made this iteration we built the appliance to be very long. With this in mind and the idea that we wanted to 3D print the housing component we designed to be a two part design lengthwise. When we started printing the housing component there were a lot of problems with the connecting rods. Due to printing defects and inadequately low tolerances, the pieces were inconsistent and unable to connect with one another. From this design we started to think of other materials that we wanted to build the housing from that would keep it light and resistant.

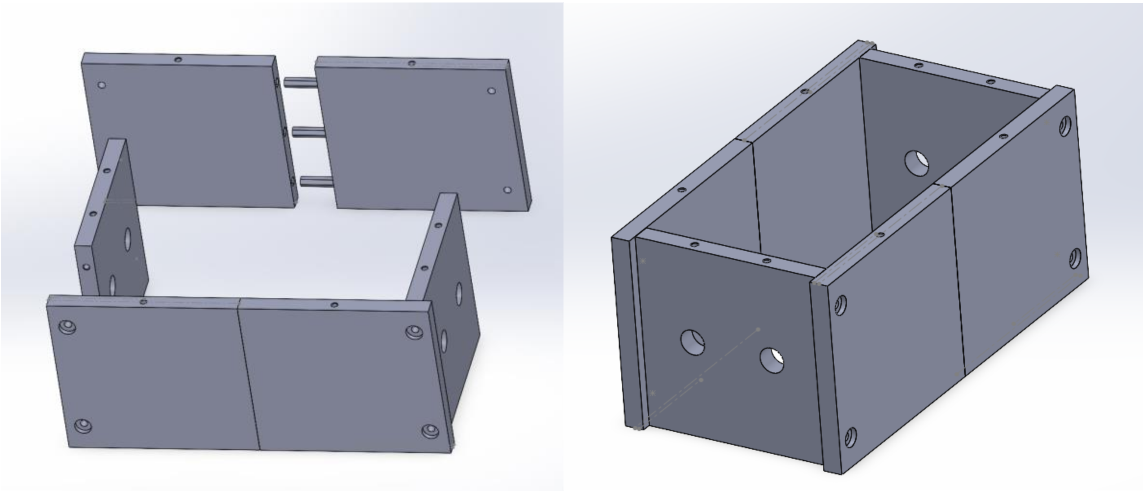


Figure 27. Second design iteration of the eru leaf shredder housing.

4.4.4 Design 3

For our third and final design, we cut the overall size of the appliance in half which opened a lot of options regarding what material to use for both the housing and the hopper. When building the smaller design we settled for wood for the housing. Since this material is known for being light and strong, we designed a housing component that had the shafts and blades secured inside of it while the gears were on the opposite side of the handle.

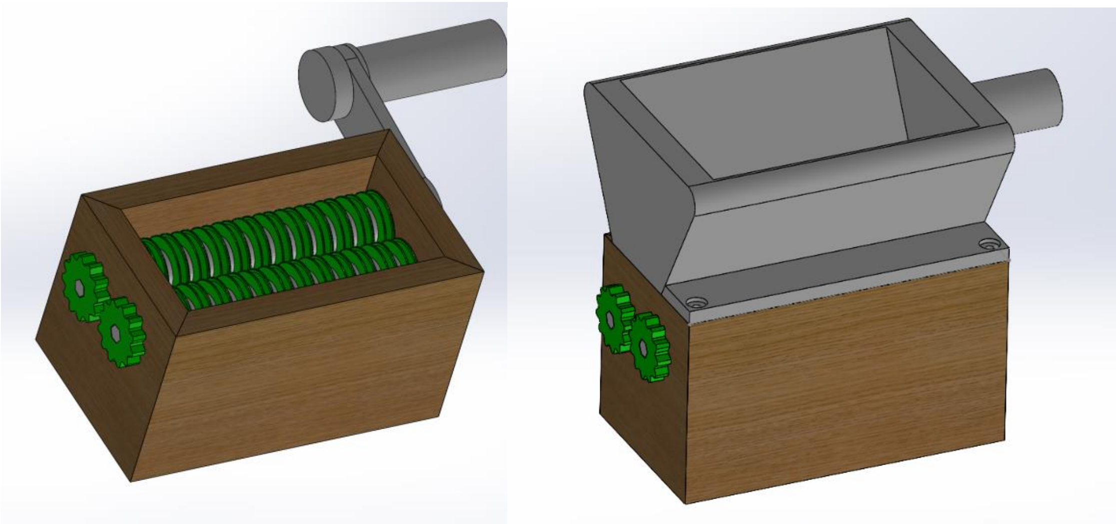


Figure 28. Final eru leaf shredder housing.

As seen in the image above we added half an inch on both sides of the walls to create a 45 degree cut to be able to put the walls together smoother. Thanks to this design, the housing component, and the in hand manufacturing, made the construction of the housing component easier since the margin of error was so low.

4.4.5 Material Choice

At the end of the designs we decided to go with wood as our material for the housing. We decided on this material since Southern Cameroon is a leading exporter of wood across the world. Since wood is readily available throughout the whole country we assumed it would be an accessible material for the community.

Chapter 5: Washer

This chapter focuses on the subsystems of the bitter leaf washer design and their iterations. As discussed previously, the main constraints for this design were water usage, time, and cost. The full list of design constraints and goals were talked about in detail in the product specification section. Dimensioned drawings for each part are included in Appendix I and a manual outlining the steps for assembly is provided in Appendix J.

5.1 Agitator

The agitator component of the washer is responsible for the applied action that removes the bitterness from the leaves. It does this using a rotational input and is expected to displace the water and leaves in a way that will most effectively complete the task. The main goal is to reduce the amount of time it takes to remove bitterness with low effort being a secondary objective.

5.1.1 Design Options

The end product takes inspiration from the agitator found in top load washing machines. The designs were compared using fluid flow analysis and a final design was created by optimizing the shape to obtain the best results.

In the design phase it was theorized that mixing and the relative velocity between the leaves and water would be the most important factors in reducing the necessary agitation time. This was later confirmed by testing. As such, the goal for the agitator design was to provide the best mixing and the highest fluid velocity at a set input speed.

5.1.1.1 Design 1

The first design was simple and included 4 triangular shaped fins at 90 degree intervals. The idea behind this design was simply to rotate the fluid within the container and did not take into account effects of mixing.

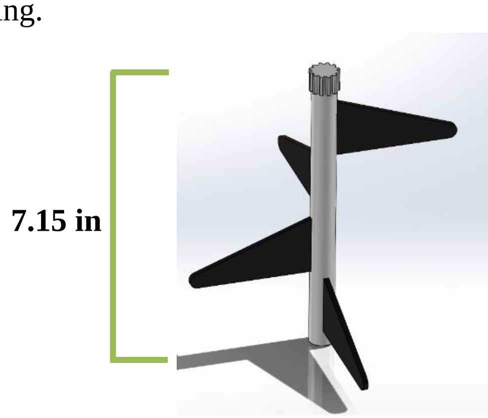


Figure 29. Simple fin design.

5.1.1.2 Design 2

The agitator design is based on the mechanism that is used in vertical washing machines to efficiently mix clothing. This design consists of two major sections: the smaller upper fin and the larger lower fin. Theoretically, this design pushes an upward flow of water on the walls of the container and a downward flow in the center. This happens as water is forced upwards by the fins, displacing the water in the center.

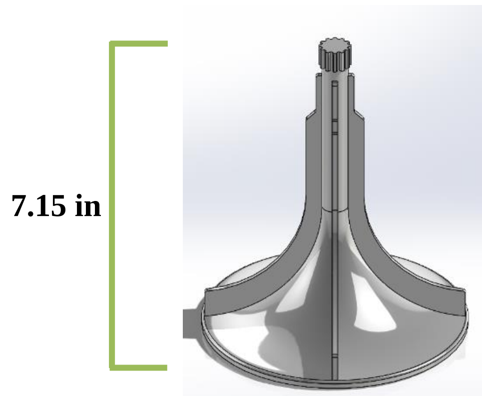


Figure 30. Second design iteration of the agitator.

5.1.1.3 Design 3

The second iteration of the agitator has the same overall design as the first, but an increase in width. The upper sectional fin is twice as wide at 0.45 inches. The lower fin is also larger at 0.80 inches as opposed to 0.60 inches. The bottom base width is the same for both designs. The dimension changes were a result of optimization through fluid flow analysis. While the previous design was purely based on previous solutions and theoretical flow, the final design utilized fluid flow calculations to form an efficient solution. While fluid flow was important in the design, it was also vital to minimize the size of the agitator to avoid filling too much volume within the container which would prevent larger amounts of Bitter Leaf to be washed.

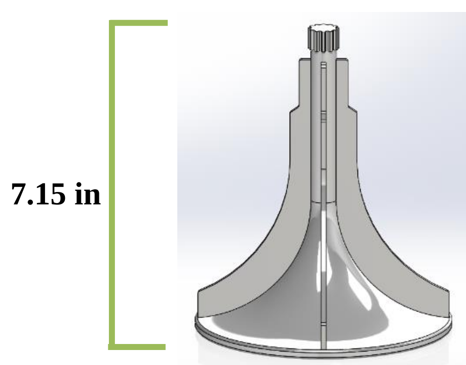


Figure 31. Final, revised agitator design.

5.1.2 Fluid Flow Analysis

The analysis for each design consists of 4 parts: general, lower, middle, and upper flow. The rotational velocity is set to 80 rpm for each analysis and the containers are filled to the top with water.

The general flow analyzes the flow of water inside the container from a vertical planar starting point. The result is a flow trajectory that shows how water flows around the entire design. This does not provide much insight other than flow velocities at different heights and radial distances.

The lower flow uses a horizontal planar starting point that is at the very bottom of the container. This shows how the water at the bottom of the container will move. The goal is that the flow trajectory shows the water rising, thus causing a mixing motion as the leaves are transported back up towards the top of the container.

The middle flow uses a horizontal planar starting point in the middle of the container. This shows how the water in the middle of the container will move. The goal is that the flow trajectory shows the water both rising and falling, meaning the leaves will be transported both upwards towards the top of the container and downwards towards the bottom of the container. This would show a mixing motion for the leaves.

The upper flow uses a horizontal planar starting point towards the top of the container. This shows how the water at the top of the container will move. The goal is that the flow trajectory shows the water falling towards the bottom of the container. This would represent a mixing flow.

5.1.2.1 General Flow

At first look the general flow for the original simple fin design looks adequate. The flow appears to be along the entire height of the container and has a good flow velocity. This, however, does not show the mixing characteristics of the design as you cannot see how the flow is moving vertically. The maximum flow velocity for this design is 1.195 m/s.

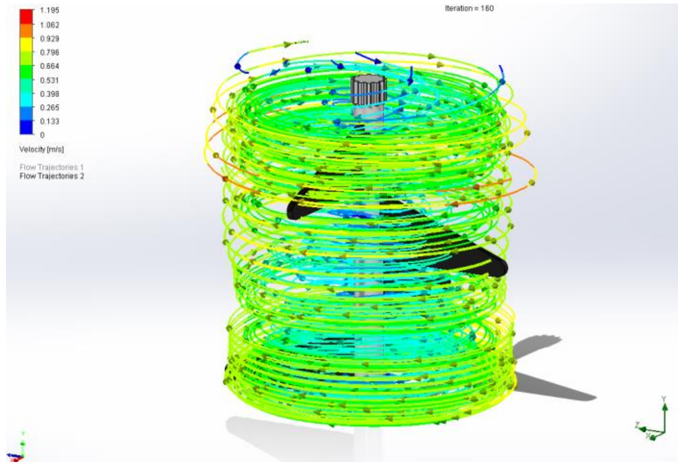


Figure 32. General fluid flow using the simple fin design.

Looking at the next iteration, the agitator design, again the flow characteristics are hard to see. The flow has a high velocity of 1.213 m/s on the outer edges of the container. The top view shown in Figure 34 shows the distribution of the flow velocity radially. The flow velocity increases radially which is an indication of solid body flow. This subject is discussed more in section 3.

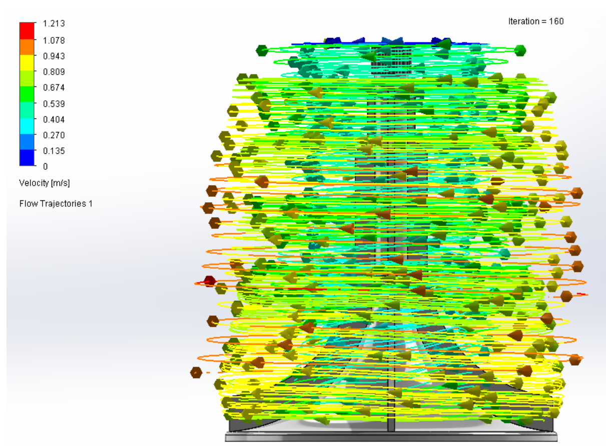


Figure 33. General fluid flow using the agitator design (side view).

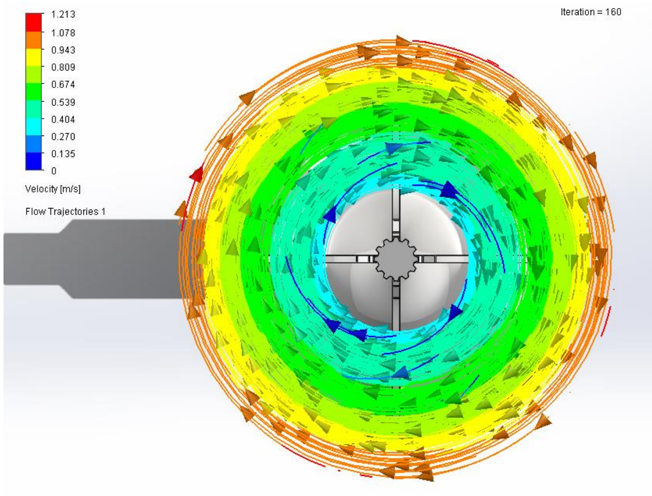


Figure 34. General fluid flow using the agitator design (top view).

Finally for the revised agitator, the general flow appears to be similar to the other fin types in this analysis, however, later analyses will show they are quite different. The maximum velocity with this design is 1.217 m/s.

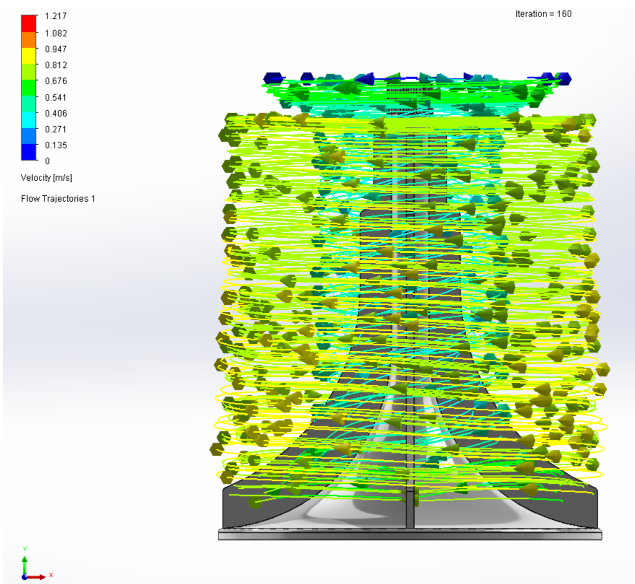


Figure 35. General fluid flow using the revised agitator design (side view).

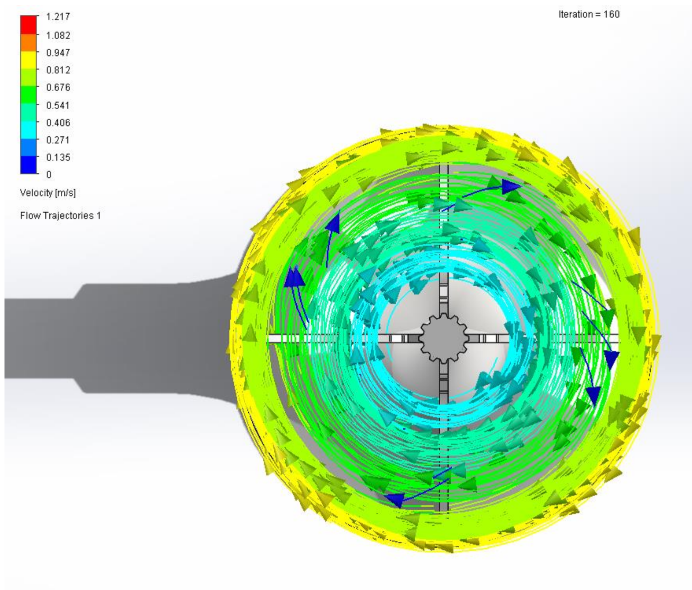


Figure 36. General fluid flow using the revised agitator design (top view).

5.1.2.2 Lower Flow

The lower flow analysis is where the differences between the three designs start to become evident. For the simple fin design, the flow velocities remain at the bottom of the container, indicating that the flow does not travel vertically. Vertical flow is important for mixing and, as it is not present here, this design is not adequate.

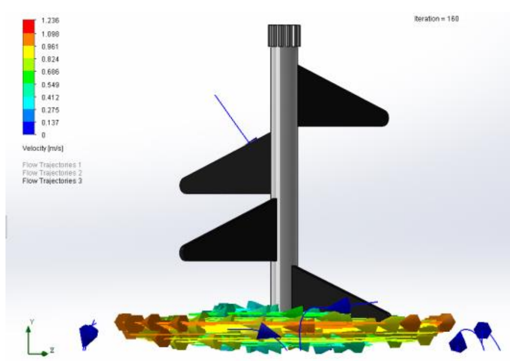


Figure 37. Fluid flow from the bottom of the container using the simple fin design.

The next iteration of the agitator design shows that the fluid from the bottom of the container rises up about halfway. This fluid motion indicates that there is mixing as the fluid at the bottom of the container rises causing a circular motion of fluid falling in the center and rising along the edges.

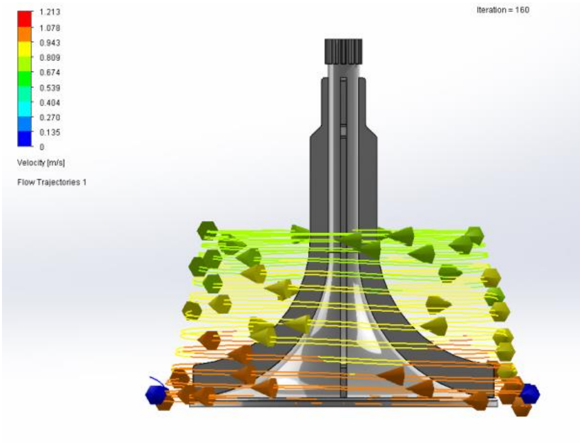


Figure 38. Fluid flow from the bottom of the container using the agitator design (side view).

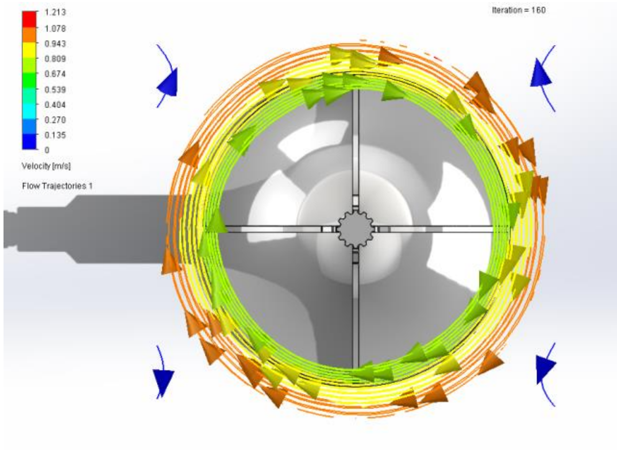


Figure 39. Fluid flow from the bottom of the container using the agitator design (top view).

The revised agitator yielded the same mixing effect but more effectively as the fluid from the bottom of the container rises much higher. This is shown in the figures below.

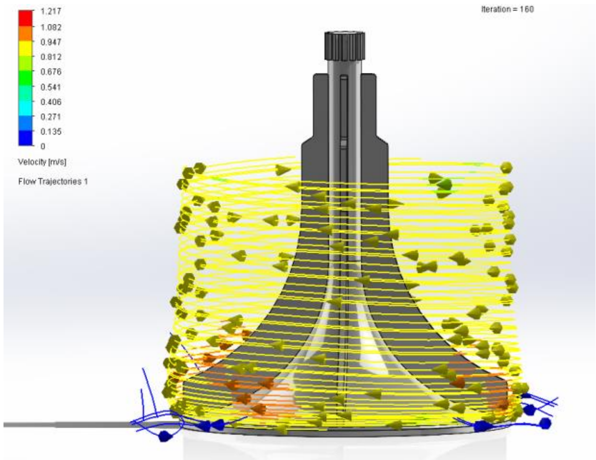


Figure 40. Fluid flow from the bottom of the container with the revised agitator design (side view).

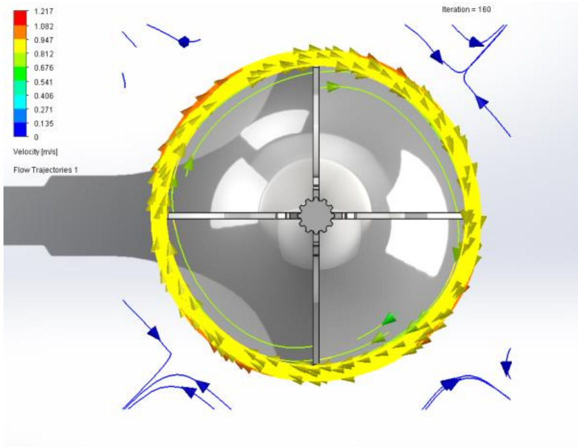


Figure 41. Fluid flow from the bottom of the container with the revised agitator design (top view).

5.1.2.3 Middle Flow

The flow from the center of the agitator is expected to both rise and fall to indicate mixing. Looking at the second design iteration, it is evident that this characteristic is present. This indicates a good mixing motion as the circulation of fluid is present along the entire height.

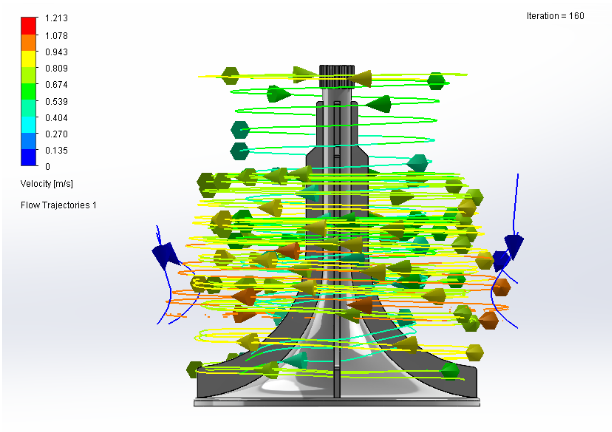


Figure 42. Fluid flow from the middle of the container using the agitator design.

The revised agitator design improves on this flow as more fluid is able to travel upwards and downwards (indicated by the density of fluid flow lines).

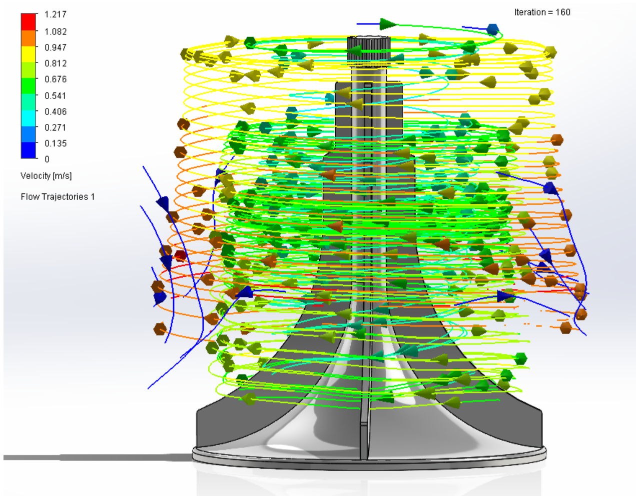


Figure 43. Fluid flow from the middle of the container using the revised agitator design.

5.1.2.4 Upper Flow

Analyzing the fluid trajectory from the top of the agitator, it is expected that the fluid will flow downward and cover the entire height to indicate good mixing. The original agitator shows some fluid dropping downward in the container, but most of the fluid remains at the top. This finding was one of the main targets for improvement in the second iteration of the agitator.

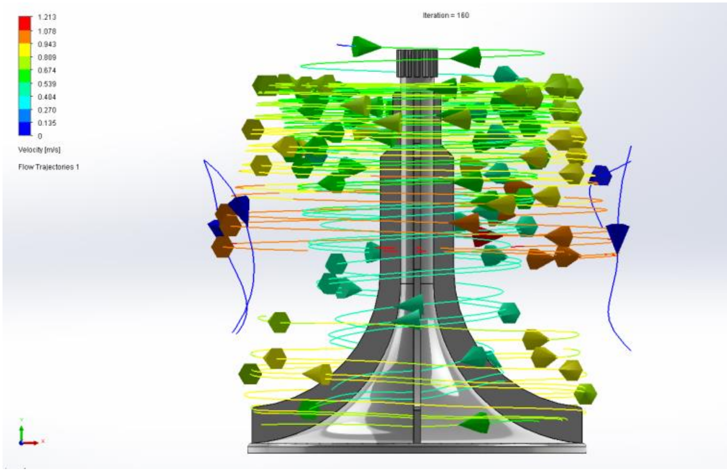


Figure 44. Fluid flow from the top of the container using the agitator design.

The revised agitator greatly improves on the upper fluid flow. The upper fin on the agitator was made twice as wide to create more of an effect on the fluid. With the revisions, much more fluid now flows downward, providing better mixing.

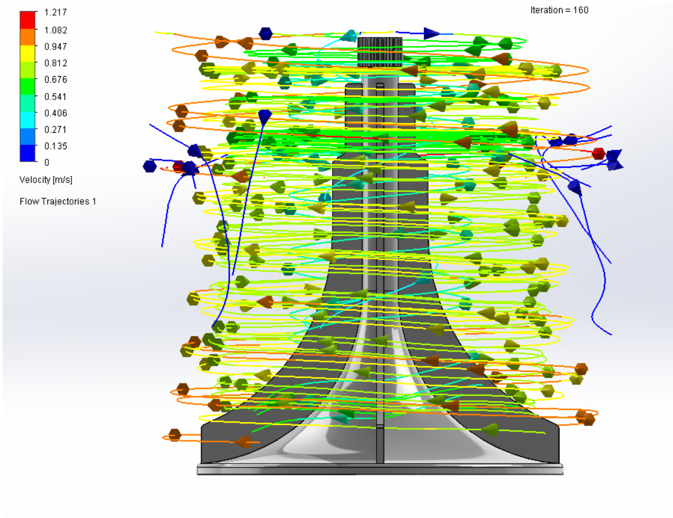


Figure 45. Fluid flow from the top of the container using the revised agitator design.

5.1.3 Further Feature Iterations

In addition to iterations of the overall design of the agitator, the shape of the crank handle mount was changed, the agitator was hollowed out, and it was made to be scalable so the same agitator design could be used for different sized containers.

5.1.3.1 Hand Crank Mount

In order to apply the rotational motion, the crank handle is attached to the top of the agitator. This was originally done using a keyed design which consisted of a circular shaft with four rectangular extensions acting as the key.

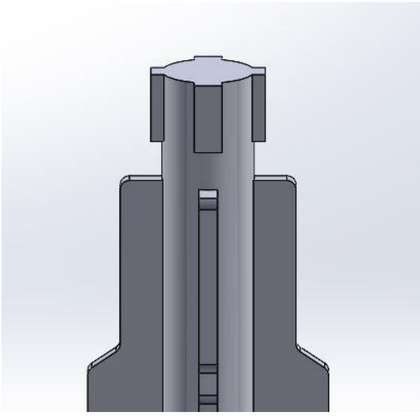


Figure 46. Original hand crank key on top of the agitator.

This design was effective but difficult to insert. In testing we found it would take a while to get the agitator and hand crank attached. To make this easier and to simplify the overall design, the top of the agitator was given a square cross-section. This itself allowed the hand crank to be attached easily and was effective for keeping the two parts together.

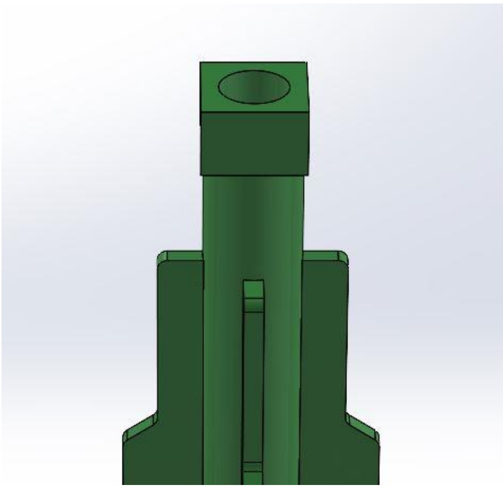


Figure 47. Final design for hand crank key on top of the agitator.

5.1.3.2 Hollow Design

Early in testing we discovered that the agitator would float when placed in the bucket with water. The interior of the agitator had a low infill to save material and this meant the part was less dense than the water. This made it extremely difficult to use the device, having to apply a downward force on the crank while spinning, and it meant that leaves would easily get trapped underneath the agitator. To mitigate this issue, the agitator was redesigned to have a hollowed interior. A hole was created at the top so water can be inserted into the agitator and prevent it from floating.

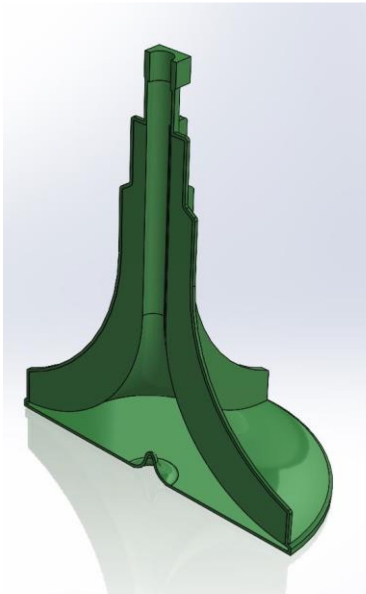


Figure 48. Sectional view of agitator, showing hollowed interior.

5.1.3.3 Scalability

With an objective of allowing the design to work with various size containers, the agitator needed to be scalable. This was accomplished by utilizing the "Scale" function in SolidWorks. To ensure minimal components would be affected by the scaling, the scale is only applied to the main body of the agitator. The top and bottom mounting points remain unaffected when scaled and only the agitator mount must be scaled so its diameter matches the bottom of the new container.

A manual was created that outlines the steps to properly scale the agitator for different sized buckets and is included in Appendix K.

5.1.4 Alternate Design Research

In addition to different fin designs, alternate appliance designs were considered. The vertical design with the revised agitator seems to create a good mixing flow, however, it is possible that a solid body flow generates. To wash effectively, the user would need to reverse the spinning direction, possibly repeatedly, to maintain the mixing flow.

One possible solution would involve placing “baffles” around the edges of the container. This is a proven method used to mitigate solid body flow and sloshing in tanks. An example is shown below in the figure below. This solution, however, would present adverse effects which make it unreasonable. Not only would the added baffles increase complexity, but they also would also decrease the volume of the container further.

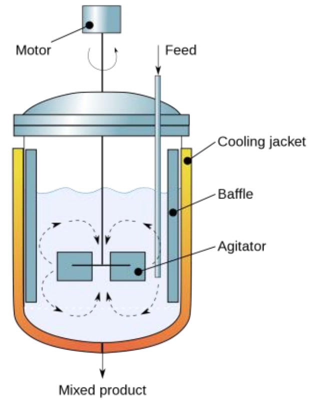


Figure 49. Example illustrations of baffles being used to prevent solid body flow [15].

An alternate design would involve a horizontal container as shown in the figure below. The fins would attach to the container around the edges and promote a tumbling flow similar to what is used in a front-load washing machine. This method will eliminate the effects of solid body flow and can reduce the volume of water required to wash the leaves.

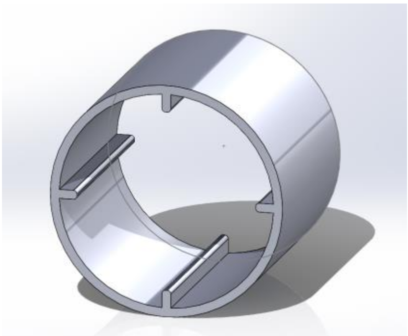


Figure 50. Horizontal container design with four integrated fins.

The FEA produced in the figure below shows the velocity trajectories if the container was completely filled with water. Ideally the container would only be partially filled, however the available fluid flow programs did not support this type of analysis. The overall fluid flow and velocities were examined and were indicative of good mixing however the horizontal architecture was further evaluated and determined not to be as adequate of a solution as the current vertical method. A horizontal design would require a large base to support the container and overall increase the complexity of the system dramatically.

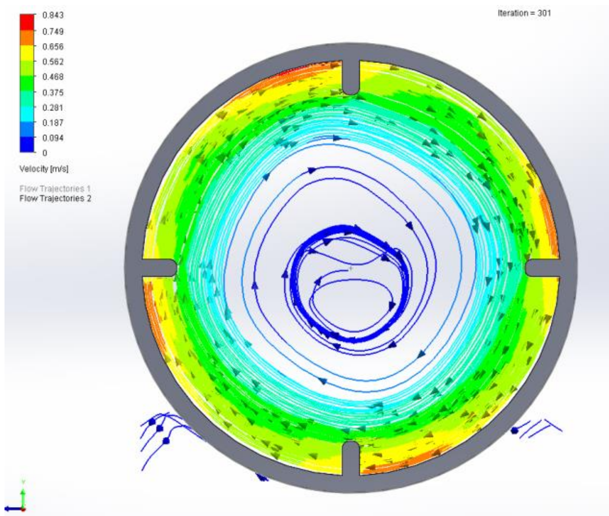


Figure 51. General fluid flow for the horizontal container design.

5.1.5 Material Choice

Most of the parts for this appliance will be made using a 3D printer. The best material choice for this method was determined to be food safe PLA plastic. Since this appliance is designed to be used with room temperature water, this material has an adequate melting point of about 180 degrees celsius. Additionally, PLA is food safe as it does not contain any toxins that could be released. That being said, the material is porous so there is a potential for bacterial buildup after repeated use. To mitigate this, a food safe silicone sealant is used to coat the entire part. This fills in any gaps in the printed part and creates a smooth surface to avoid bacterial growth.

5.2 Agitator Mount

The agitator mount is designed to give the agitator a base to spin on with minimal friction and high stability. The agitator must be able to spin freely so as to not increase user effort and must be stable so that the appliance works most effectively and is easy to use.

5.2.1 Design Options

The main inspiration for the agitator mount design comes from the mounting system that is used in the salad spinner. Similarly, this appliance has an interior rotating part that must rotate with little friction. The mount features a small pin and the basket has a conical engraving to match. The basket sits on top of the mount and is able to rotate in place with a very small amount of friction.

The agitator mount design for the Bitter Leaf Washer uses the same features as the salad spinner with an increased emphasis on stability and adaptability. The bucket inside the salad spinner does not require as much stability from the mount because it is close to the walls of the container and spins very quickly with little external resistance so as to self stabilize. Since the agitator sits in the center of the container and is met with the resistance of the water and leaf around it, there is a higher need for stabilization to be considered for the agitator mount design.

Additionally, the agitator mount must be adaptable to different sized housings. For all of the design iterations, this was achieved by using a base that could be easily changed to match the diameter of the housing, ensuring an easy installation with the mount being perfectly centered. A manual was created to outline the steps for making this adjustment and a copy can be found in the Appendix L.

5.2.1.1 Design 1

The first agitator mount design featured a tall pin with a similarly deep hole in the agitator to match. The idea behind this was that it would increase stability due to the increased surface area on the sides of the pin and thus more contact area. Testing showed that this did not adequately increase stability and only raised concerns for durability.

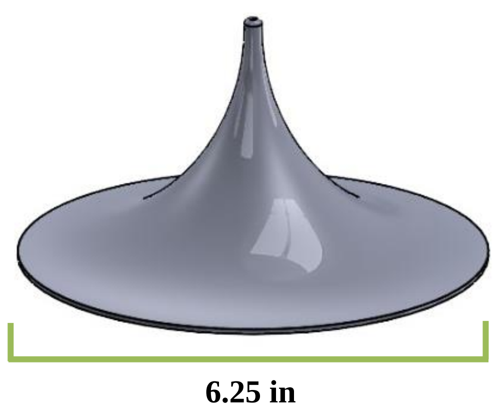


Figure 52. First agitator mount design.

5.2.1.2 Design 2

The size of the pin was dramatically decreased for the second agitator design which provided similar stability and a much cleaner overall design. In testing it was found that the stability was not adequate and leaves would even get stuck underneath the agitator.

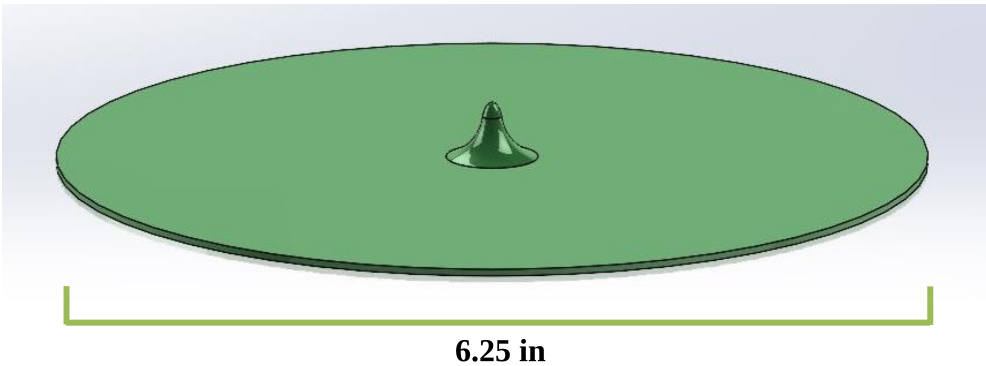


Figure 53. Final agitator mount design.

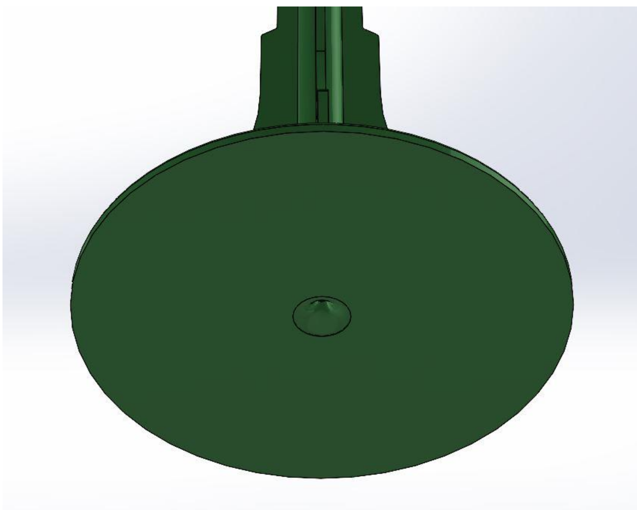


Figure 54. Insert for the agitator mount's pin in the bottom of the agitator.

5.2.1.3 Design 3

The overall design of the mount remained the same in this iteration, however the stability was increased by decreasing the gap between the bottom of the agitator and the mount. Past designs had a smaller hole in the agitator to allow for a gap to decrease friction. The final design for the agitator mount no longer featured this gap so the bottom of the agitator would rub on the agitator mount. Since this is a plastic-to-plastic interaction, the increase in friction was minimal and the system became significantly more stable.

5.3 Housing

For the housing component for the washer we had a few ideas for the design. The change in design came in more on the design of the blades not on the design of the housing. We had already decided to make the design of the housing to be a cylinder so we chose a bucket to be our main housing component.

5.3.1 Design Options

For the first design iteration as shown below we have the housing component to be a 2 piece housing component with the keyed component of the blades connected to the handle.

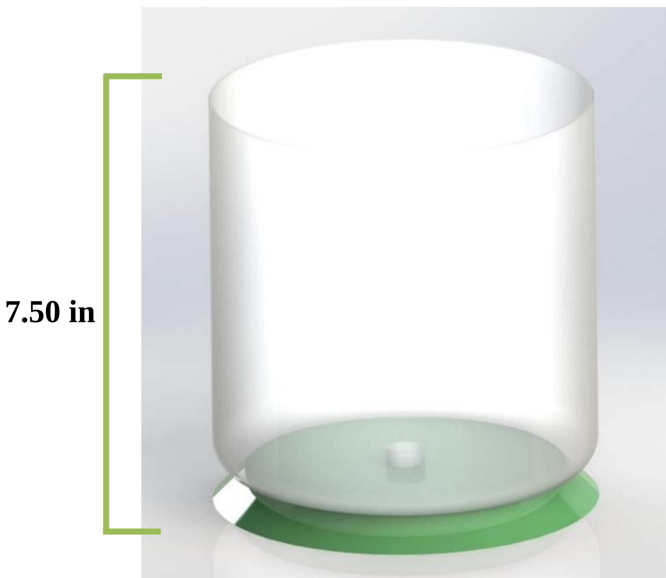


Figure 55. Original bitter leaf washer housing.

Figure 56. Original bitter leaf washer lid.

As shown in this image we have the two pieces of the housing component and how we wished it was built.

Due to our project needing to be frugal and be easy to build and maintain we decided to buy food safe plastic buckets instead of building the housing components ourselves. Buckets are an accessible resource in Cameroon and using this allows the user or manufacturer to decide the best volume for their use case and use a scaled version of the washer parts we created. This scaling process is outlined in scaling manuals we created for the agitator and agitator mount which can be found in Appendices C and D.

Figure 57. Bitter leaf washer bucket.

As seen from the picture above we bought a bucket with a sealable lid so the water could stay inside of the bucket and have no problem moving the bucket around. A hole is cut in the center of the lid for the handle to slot through and connect to the agitator.

Chapter 6: Testing

The following chapter discusses the testing that was completed for the eru leaf shredder and bitter leaf washer appliances. Each device went through a series of tests to help identify areas for improvement and quantify the final results of the products.

6.1 Eru Leaf Shredder Testing

Once we produced a physical model for the first design of the shredder with the three prong blade, we began to test its shredding ability. For this test, spinach was used as eru leaf could not be sourced. Spinach has a similar texture and size to eru leaf and was identified to be a suitable replacement for testing.

Figure 58. Comparison between design 1(left) and a paper shredder (right).

As seen in the image above the prototype did not create clean cuts as compared to a paper shredder. One of the first problems we had in the testing is that we didn't have the housing complete for it. So when we started spinning the handle the two walls supporting the shafts would wobble and start falling since there was no support. Another problem we noticed was the thickness of the blade, since the blade was thicker than what we wanted the size of the cut to be, it was impossible to create a continuous small fluid cut with a blade that was that thick. The third problem was that due to only having 3 teeth and not having stability or speed to make the blades move smoothly, the blade was only piercing the leaf and not making any significant cuts into the leaf.

For the second test, we changed the blade completely but kept the same machine size, we made the blade thinner and added more teeth to look more like a shredder blade. This change in the blade made a major impact in how thinly it cut the leaf. We also changed the configuration of the blades to be in between each other so that the separation between blades was the size that we wanted the cut to be.

Thanks to this separation in between the blades, and reducing the thickness of each blade it finally started doing consistent cuts throughout the leaves. One of the problems we faced was the same as the last test, the housing wasn't complete but it gave a significantly better result than the first design.

For our final design we cut the whole size of the machine in half. Since the eru leaf is not a big leaf and reducing the size of the machine would help with ease of use and weight. As shown in the table below, we can see the difference in thickness between the different sizes of blades and our results of the several tests.

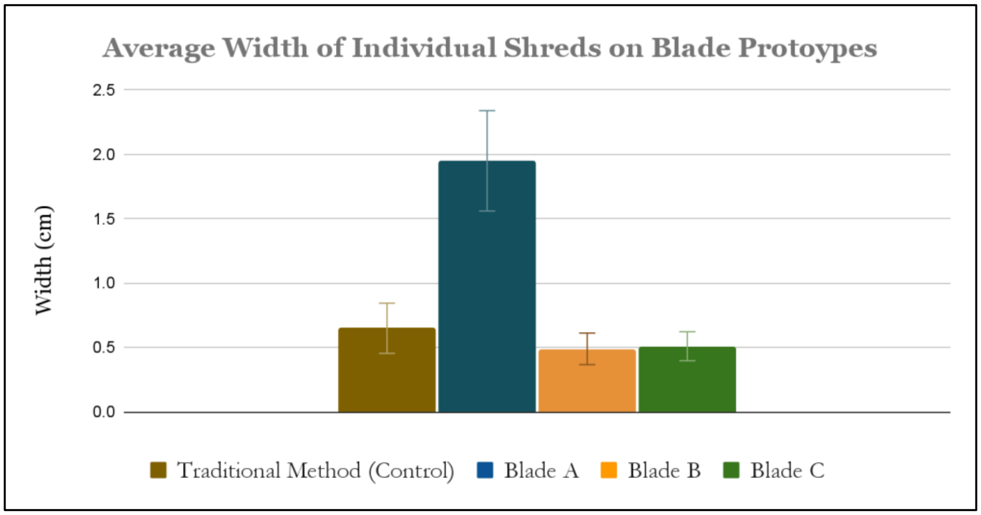


Figure 59. Thickness comparison between our blade designs and the traditional method.

As shown in the above figure, our first design did not come near to the size used in traditional meals, for our second design we can see that it cut the leaves to the desired size wanted by the user. For the third and final design we added a hopper at the top of the housing component to create an easier way to insert the leaves instead of doing one by one.

The last test that we did was to reduce the time of the traditional method by at least fifty percent. Fortunately this was accomplished thanks to the second design and the time got reduced even more with the addition of the hopper on top of the housing.

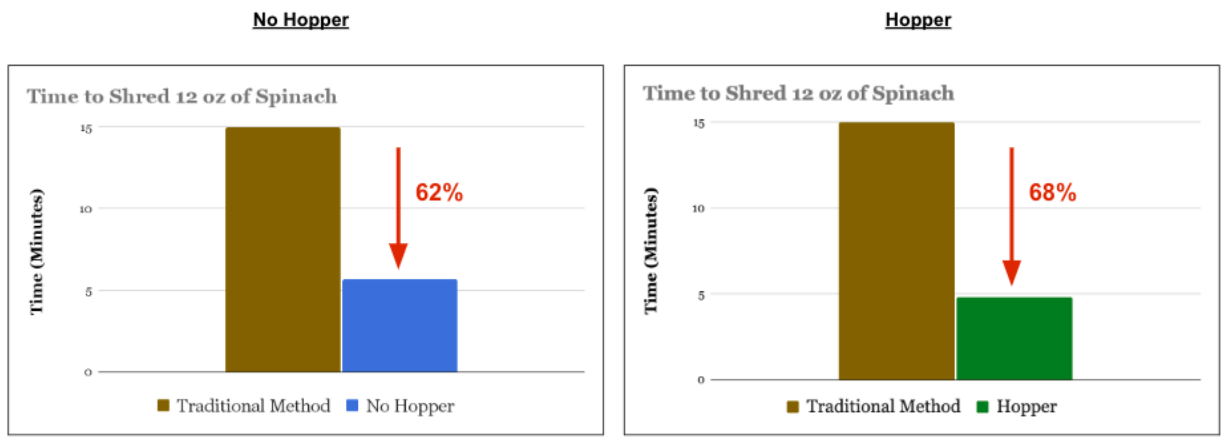


Figure 60. Comparison with hopper and no hopper with traditional method.

As shown in the two tables above the design with no hopper cut the leaves sixty two percent faster than the traditional method and when adding the hopper that time got reduced to sixty eight percent. After several design iterations and testing the different designs we were able to accomplish the goals that we set for this appliance.

6.2 Bitter Leaf Washer Testing

Once we had a physical prototype of the bitter leaf washer constructed, we began testing to see if the design was effective and guide design iterations. This section outlines the testing process and results.

6.2.1 Quantifying Bitterness

Prior to testing the washing design, it was necessary to determine how we would measure the necessary metrics. The amount of water, bitter leaf, and limestone could all be quantified by volume. The main metric that we were testing for, bitterness, is not as easy to quantify. To come up with the best method for measuring this, research was conducted to determine what causes the bitterness and how it is measured in existing methods.

Bitterness can be the result of many different factors depending on the exact food. Commonly, bitterness is the result of plant-derived phenols, polyphenols, flavonoids, catechins, or caffeine. Acidity can also have a slight effect on bitterness but is not commonly used to measure it. One of the most widely used bitterness tests is done using “international bitterness units” or IBU. This is used to measure the bitterness of beers and is done by measuring the amount of iso-alpha acids by spectrophotometry.

In bitter leaf, or as it is scientifically known Vernonia Amygdalina gets its bitterness from alkaloids, saponins, tannins, glycosides, and phenolic acids [16]. Existing bitterness tests are very specific to the substance it is testing and is most easily done when there is a single contributing factor that dominates. Bitter leaf has many factors that cause its bitterness and there is no current method for measuring these easily. Brief research was conducted on how we could measure the components found in bitter leaf however it was clear that this would be an extensive process that required advanced methods and extracting the individual components would take days to complete [17].

A study conducted in 2013 sought to measure bitterness of 15 topical African leaves [18]. This was done by quantifying its "bitterness value" which involves a taste testing method where the bitterness is compared to other known bitter tastes and rated on a scale. This is the method we chose to use as it would allow us to get results quickly and easily while still being adequately accurate for our testing purposes.

6.2.2 Procedure

Prototypes and part revisions were tested using the following procedure. Each test used a constant amount of bitter leaf, water, and limestone while varying the time, agitation level, and temperature of the water. Two cups of bitter leaf were used for each test, equal to four servings. This volume was used as it corresponds to the average family size in Cameroon. Decreasing water usage was one of the main goals with this appliance. We decided to use a quarter gallon of water in our testing as this corresponds to a typical volume used in the traditional method. The traditional method uses about four of these rinses, resulting in one gallon of water used to remove the bitterness from the two cups of bitter leaf. Our goal was to only use the initial quarter gallon of water without needing to rinse out the water. Finally, half an ounce of limestone was used.

The test procedure involved intervals of time where the bitter leaf would be washed. Before washing and at the end of each interval, the bitterness was evaluated by picking random leaves from the mixture and having each group member taste them. Raw cacao, coffee, spinach, and milk were all on hand to use to evaluate the bitterness in relation to other known substances. Each group member assigned the bitterness level to a corresponding value on a scale we created from 1 (not bitter) to 8 (extremely bitter). This scale can be seen in the figure below.

Table 5. Bitterness scale used for testing.

Bitterness Scale							
1	2	3	4	5	6	7	8
Not Bitter	Slightly Bitter	Less Bitter	Neutral	Somewhat Bitter	Moderately Bitter	More Bitter	Extremely Bitter
Milk		Spinach		Coffee		100% Raw Cacao	Bitter Leaf

An example of the data collection table used for each of these tests is shown below. This shows the time intervals used, typically 5 minutes, and has spots for each group member's evaluation of the resulting bitterness which are then used to calculate the average perceived bitterness for that interval.

Table 6. Example data collection table used to evaluate bitterness for various methods.

Method						
Time Elapsed (Minutes)	Person 1	Person 2	Person 3	Person 4	Person 5	Average Bitterness
5						
10						
15						
20						

Initial tests were run to determine bitterness levels for soaking the leaves with no agitation and using the traditional method of scrubbing the leaves by hand. Despite the goal of the appliance to be used for room temperature water, the impact of temperature was evaluated by washing the leaves with no agitation in boiling water to understand an idealized case. The appliance design then came into effect for testing agitation as well as a high agitation using a geared version. Finally, increased agitation was attempted by adding different sized balls to the mixture.

6.2.3 Results

The results from altering temperature with no agitation showed that boiling water was significantly more effective at decreasing agitation than room temperature water. After just 15 minutes, the boiling water had completely removed the bitterness from the bitter leaf. As we will discuss later, this is even more effective than washing the leaves with agitation at room temperature. It was also noted that boiling water had a much larger effect than just hot water. We believe this is attributed to the motion boiling water provides as gas bubbles form at the bottom of the container and float to the top. This essentially creates its own internal agitation which, teamed with the high temperature, greatly reduces the amount of time it takes to remove bitterness. The results of this experiment are summarized in the figure below.

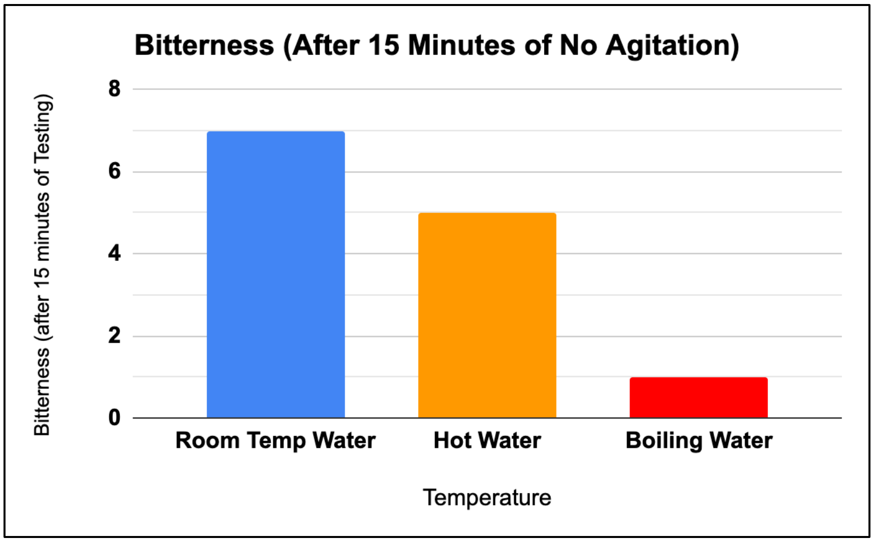


Figure 61. Bitterness level after 15 minutes of soaking in room temperature, hot, and boiling water.

Agitation speed was then tested using the standard design, which inputs rotation to the agitator through the hand crank at a 1:1, and a geared design which inputs rotation at a 2:1 ratio. Ultimately this means that the geared agitator spins twice as fast, increasing agitation. The geared design removed bitterness slightly faster, taking about 20 minutes compared to 25. This was compared to results from the traditional method which took 55 minutes to completely remove bitterness. The results from this experiment are summarized in the graph below.

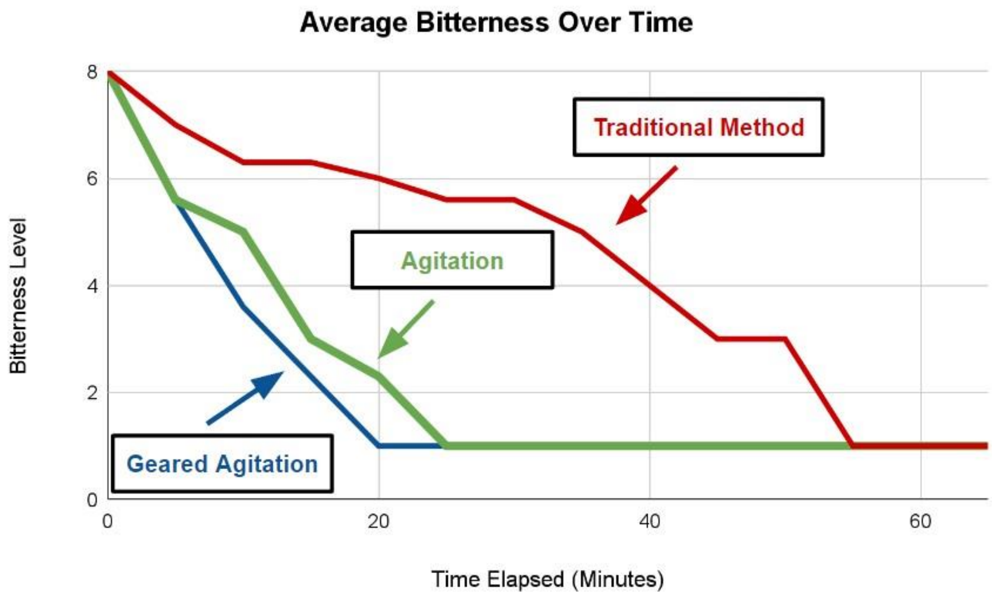


Figure 62. Results from geared agitation, regular agitation, and the traditional method.

Although the geared agitation was quickest, we decided not to pursue this design as it increased the overall complexity dramatically. The main goal of this project was to create simple designs that would be inexpensive and require little to no maintenance. The simple agitation design reduced the necessary washing time by more than 50% and saved 75% in water as it only required the initial quarter gallon and no rinses.

In an attempt to increase agitation without making the system too complex, different size balls were added to the container. It was theorized that the balls would interact with the leaves in the mixture and provide a further scrubbing motion. This was done using golf balls as well as different size and density bouncy balls. Results showed that this actually increased the amount of time it took to remove bitterness so this was not used in our final product.

Chapter 7: Cost Analysis

The final designs for the eru leaf shredder and bitter leaf washer are both relatively inexpensive to produce. The bitter leaf washer ended up exceeding cost expectations while the eru leaf shredder required a slightly higher price point due to the larger size of the printed components.

7.1 Eru Leaf Shredder

The final prototype of the eru leaf shredder was determined to cost $15.98. The majority of this cost comes from the PLA required to print some of the parts. The large quantity of blades and spacers and the large size of the hopper mean that over 300 grams of PLA is required for each shredder. Additionally, the wood required for the housing of the appliance can be costly. The full cost breakdown for the eru leaf shredder is shown in the table below.

Table 7. Cost analysis of eru leaf shredder.

Component	Material	Price (USD)
Hopper:	180 g PLA	$6.28
Shaft, Blades & Spacers Assembly:	94.64 g PLA	$3.42
Handle:	29.82 g PLA	$1.08
Gears:	5.45 g PLA	$0.20
Housing:	1/2in x 3ft Wood	$5.00
Total:		**$15.98**

7.2 Bitter Leaf Washer

The final prototype of the bitter leaf washer was determined to cost $5.74. The majority of the cost in this case comes from the bucket used as the container, making up $4 of the price. The price is largely dependent on the size, the prototype used a 1-gallon bucket, and where it is bought from. It was also noted that buying more than one bucket would reduce the price per bucket substantially. If the user already has a bucket or similar container they wish to use, the necessary components will cost less than $2. The full cost breakdown is shown in the table below.

Table 8. Cost analysis of bitter leaf washer.

Component	Material	Price (USD)
Agitator:	100 g PLA	$1.00
Agitator Mount:	30 g PLA	$0.33
Crank:	38 g PLA	$0.41
Bucket:	Food-Safe HDP	$4.00
Total:		**$5.74**

Chapter 8: Engineering Standards

The shredder and washer attempt to contribute towards aiding in the effects of poverty and displacement within the rural South Cameroon regions. They need to be simple and affordable, without taking away from the functionality of the devices. The design incorporates easily sourced and affordable materials that are able to perform in the climate of the region. We conducted research through forms that were sent to rural communities and gathered information from our South Cameroon contact. From the data accumulated, customer needs were determined. The designs focused on cost efficiency, simplicity, and safety. Thus, the devices were engineered with these goals in mind, and proper solutions were developed. Our project, ideally, would have a significant social impact that would improve the food production process in the rural South Cameroon region. The shredder and washer provide a means for which eru and bitter leaves may be sliced and washed, respectively, with the aspects of the region's cultural food preparation and diet kept in mind. The team, when regarding the implementation of the design goals, decided that the engineering standards most important to our project are geometric dimensioning and tolerances, ethical design practices, and health and safety.

8.1 Geometric Dimensioning & Tolerances

During the production and design processes, we followed the industry and governmental standards with regard to the drawing, dimensioning, and tolerancing performed during the project. During the design process, we used the proper engineering drawing requirements. We implemented standard dimensioning and tolerancing requirements by labeling and establishing the tolerances on each part. For example, in Figure 63, the dimensions are labeled with the dimensions and views that we felt were more important.

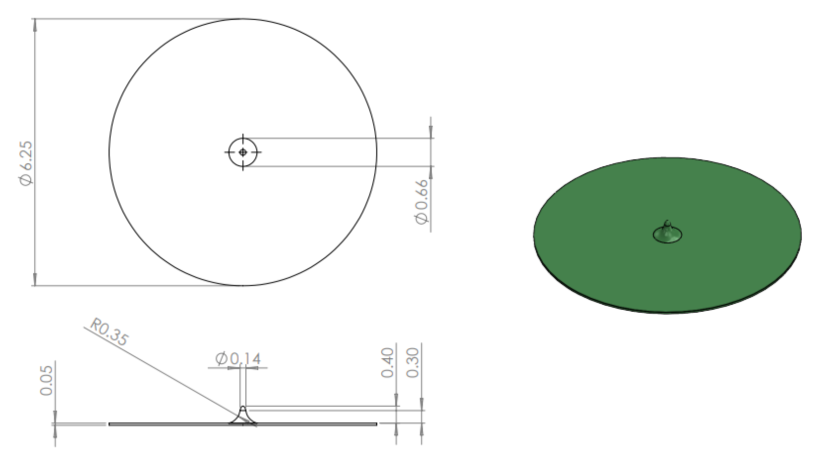


Figure 63. Dimensioned part from washer device.

The tolerances were considered for each part of each device. We researched tolerances for 3D printing and determined proper measurements as a result. The tolerances for all parts are 0.01, which is defined in the bottom right corner of each SolidWorks drawings that provide spaces for the information.

Every part and subsystem is listed within the drawing in the top right corners. For ASME standards, it is important to communicate all necessary information. Each part has its own independently toleranced and dimensioned drawing, but all parts are included within an assembly drawing, for example as seen in Figure 64.

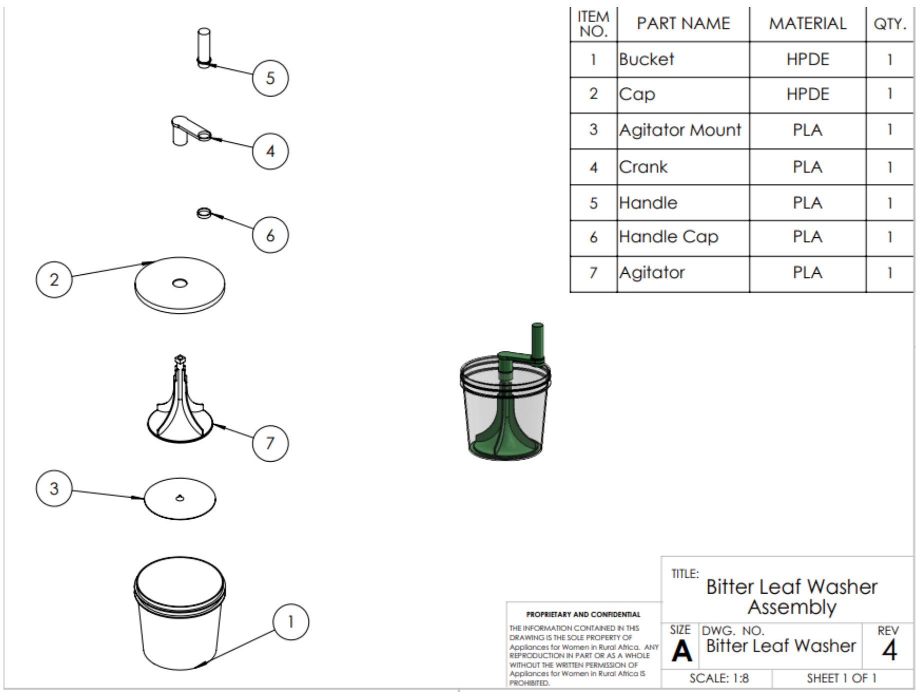


Figure 64. Assembly drawing of washer device (see Appendix I, Figure I1).

8.2 Ethics

The project's humanitarian circumstances required us to look outside the scope of physical and economic constraints, and also consider environmental, political, and cultural constraints. Our design specifically targets women in underserved communities in South Cameroon, but has implications for anyone in rural, low income communities across the world. Understanding the impact we are having on our critical consumers' lives has helped us lead the project with integrity, character. Most importantly, the team aimed for the project to meet ethical standards under considerations of the Rights and Justice lens. These frameworks have served as guidance tools when navigating the ethical dilemmas we face as a team, many of which require us to analyze the issues on a more profound level, beyond the surface level impact.

There are several reasons we have chosen to analyze our project primarily through the Rights and Justice Lens. The principles of this ethical lens align best with our project because of its focus on the community. Our project centers around the need for a frugal product in a rural community. Given the nature of working with rural and low income communities, accessibility was a priority for us in this design. Although the manufacturing and distribution of the product is a responsibility of the non-profit organization partners, it is our duty to design the product to be as easily manufacturable as possible, which will in turn increase accessibility.

Conscious that we are designing a frugal tool, our goal was to design it to be as affordable as possible without sacrificing the quality of the products. To achieve this, we are using mixed media to complete the builds of the project with the intention of reducing the use of materials that are costly and difficult to manufacture. We have allocated part of our budget to purchase our own 3D printer to decrease prototype production time and gain a better understanding for the best materials and design. Our intentions are to hand off the printer to the Victoria Relief Foundation as part of the final project in order to aid with the manufacturing process.

The team has conducted multiple rounds of testing to produce the best design and ensure that the product works as intended. Through each round of tests, we altered the design physically, and updated our virtual design using CAD software. Our goal is to hand off a viable product to the technicians who will be producing this product. In the case that an engineer would want to further develop the product, they will also have full ownership and access to the CAD renderings and models.

The use of plastic calls for us to analyze the environmental impact on our products. On a per-use basis, the machines produce little to no waste. However, once they are no longer functional, there are multiple components that require proper and careful disposal. The 3D printed parts are all made of PLA and can only be disposed of at special facilities. Unfortunately, these facilities are not easily accessible for the primary users of the products, which means the components will likely go to waste. The nature of the appliances also introduces hazard points for the user such as the sharp blades used in the shredder. It is important that any risks are evaluated and the appliances are designed to be as ecofriendly and safe as possible.

The women that form part of the communities in rural South Cameroon are individuals who have their own values, goals, and interests that they can seek at their own will without interference from others. During interviews, many women mentioned that they enjoyed their daily work. They expressed a desire for a tool to help them accomplish this in an easier way, but also communicated that they found comfort in the tradition and routine of preparing these foods.

Despite the traditional methods being long and arduous, it is currently all they have that will give them the outcome they want. As engineers, this pushed us to design a process in which the final result of the shredded leaves was to be in the accustomed fashion.

We were careful to consider this need in our design process for the shredder, and made the small size of the shredded leaves a requirement. Through the design of this product we hope to promote their individuality and seek to help them achieve their goals and empower them as entrepreneurs in doing so.

8.3 Health and Safety

Health and safety take precedence over every other consideration. Engineers must always understand the implications of their projects and interpret what effect any device developed has on its surroundings and consumers. Dangers must always be completely mitigated during all portions of an engineering project. With that in mind, we looked at possible health and safety concerns during the design process to be better prepared to solve potential hazards further along in the manufacturing and development process.

The devices are constructed using FDA approved material that are safe for food processing. Because our devices deal with food, public health requirements guided much of the design. As both devices deal with food that is intended for consumption, it was important to factor this into future implementation. In addition, the shredding device uses blades with a narrow and confined housing space. Seeing this as another potential hazard, the shredding device's blades and axles are contained within a compartment like structure with a hopper blocking this only entry point.

Health and safety are not only mandatory but imperative if a safe, technological society is to function properly. People live within a society with constant innovation, which may lead to harmful situations if precautions are not taken during all parts of the engineering process.

Chapter 9: Summary and Recommendations

The eru leaf shredder and bitter leaf washer appliances created in this project seek to reduce workload for women in rural areas of Cameroon. In this chapter we go more in depth on the final designs and suggestions for improvement from outside sources and internal reflection. Future considerations as well the key takeaways of the project are also discussed.

9.1 Overall Evaluation of Design

The final design of the eru leaf shredder is efficient and easy to construct by one person with little instruction. Additionally, the appliance is shown to be a cost-effective solution to substantially reduce cutting time. The appliance reduces cutting time by 68% and costs about $16.

The bitter leaf washer appliance successfully achieved its goals of reducing the amount of time spent washing the leaves and reducing water usage. The appliance reduces washing time by 50% and water usage by 75%. The design is simple and adaptable as it can be scaled to fit the size of any supplied bucket, and cost effective, costing under $6.

In order to assist manufacturers, a manual outlining the steps and settings used to 3D print the parts for both appliances was created and is attached in Appendix M. Additionally, user manuals detailing the correct procedure for using the appliances were created and are attached in Appendix N and Appendix O for the eru leaf shredder and bitter leaf washer respectively.

9.2 Suggestions for Improvement

The two appliances exceeded our goals but there is always room for improvement. Both appliances contain 3D printed parts that may be difficult to produce in Cameroon. Our contact at the Victoria Relief Foundation informed us that these parts can be printed by local universities and entrepreneurs or be printed in the United States then shipped to Cameroon. Shipping these items would increase the price of our appliances and relying on a third party to produce the parts could be troublesome. We would suggest research be conducted on another way to construct these parts or get them to Cameroon without a large inflation in price.

The eru leaf slice received feedback from one of the judges at the senior design conference, stating that, while we have a lot of safety precautions for the blades, the gears are exposed creating a possible safety hazard. We suggest that an enclosure be added around the gears to shield the component and prevent injuries. As part of our own design reflection, we suggest that the lifespan of the PLA blades be considered. Some research was conducted on the lifespan of PLA parts but it is highly dependent on the design, environment, and forces.

The bitter leaf washer also received feedback from a judge at the senior design conference who mentioned that the adjustable sizing for the agitator and agitator mount may not be clear and might greatly increase the manufacturing time. As a result, we have created manuals that explain the necessary steps. While this helps manufacturers make size adjustments, it requires access to the SolidWorks software and can be tedious if adjustments need to be made often. We suggest that an easier method be developed so the scale of these parts can be adjusted on the fly. This is not as simple as adjusting the scale of the entire part as some components must remain the same size.

9.3 Key Takeaways

Prototypes for both appliances led to discoveries and ideas that improved their designs. Researching existing products and disassembling them to understand their components also assisted in the development of our appliances. Disassembling a salad spinner allowed us to understand and implement a similar design that allows the agitator of the bitter leaf washer to spin with little friction. Similarly, disassembling a paper shredder helped us understand the blade design and surrounding components that allow for efficient and clean cuts. Numerous iterations based on these features were made and tested to achieve an adequate design.

Prior to physical prototyping, the team worked collaboratively to conceptualize solutions and identify tests that could be simulated to expedite the design process and work towards a better first prototype. The agitator for the bitter leaf washer underwent fluid flow analysis which dramatically changed the approach of the design. A test was constructed to understand the parts' influence on mixing which was used to produce a design that would theoretically be most effective. Technical skills were gained through using the fluid flow simulation in SolidWorks and designing our own testing methods. This theme continued throughout the project with both appliances and for both simulated models as well as physical prototypes. The main steps and conclusions of the project were presented by the team at the senior design conference. The slides from this presentation are included in Appendix P.

Ultimately, in addition to valuable collaboration and technical experience, the team succeeded in creating two appliances that have the potential for real-world implications towards helping a community that has been affected by war and poverty.

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Appendices

Appendix A Existing Patents

Table A1. Shredder existing patents.

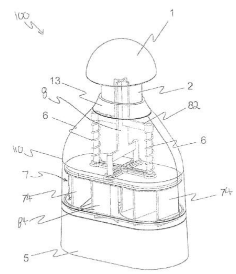
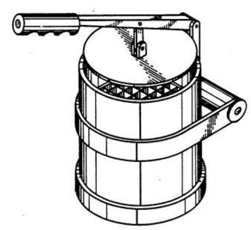
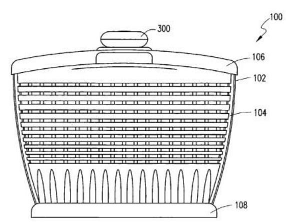
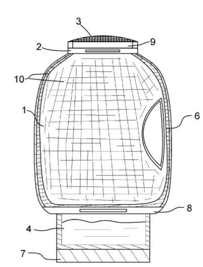
Patent Number	Name	Sketch
US20130092773A1	Food Chopper	
USD296176S	French Fry Cutter	

Table A2. Bitter leaf washer existing patents.

Patent Number	Name	Sketch
US7111546B2	Salad Spinner with Improved Drive Assembly	
US20170135527A1	Portable Fruit and Vegetable Washer	

Appendix B Customer Needs & Interview Information

Table B1. Southern Cameroon survey questions.

Southern Cameroons Food Technology User Studies Survey
1. Gender a. Female b. Male c. Prefer not to answer d. Other
2. Where do you currently live? a. Urban city in Southern Cameroons b. Rural area in Southern Cameroons c. Other
3. What age group do you fall under? a. 0-17 b. 18-29 c. 30-49 d. 50+
Eru Leaf
1. How much time does it take to slice the eru leaf?
2. What methods or tools do you use to slice the eru leaf?
3. What is the most difficult part of completing these tasks?
4. Would you be interested in an affordable tool that makes preparing eru leaves easier and less time consuming? a. Yes b. No c. Other
5. What would you like to see in this kind of appliance?
6. What is the most important factor in this kind of appliance?
Bitter Leaf
1. How much time does it take you to wash bitter leaves?
2. What methods or tools are used to wash the bitter leaves?
3. What is the most difficult part of completing these tasks?

4. Would you be interested in an affordable tool that makes preparing bitter leaves easier and less time consuming? a. Yes b. No c. Other
5. What would you like to see in this kind of appliance?
6. What is the most important factor in this kind of appliance?

Table B2. Eru leaf shredder customer needs.

Need Number	Part	Need	Importance
1	The appliance	is cheap.	5
2	The appliance	reduces the amount of time needed to slice the leaf.	5
3	The appliance	reduces the force and concentration needed to slice the leaf.	5
4	The appliance	is rugged enough to go through several wash cycles.	4
5	The appliance	is small so it doesn't take up too much space in the kitchen.	4
6	The appliance	is light enough to be able to be moved around the kitchen.	4
7	The appliance	is easy to build (so people in South Cameroon can recreate it).	3
8	The appliance	is able to slice a large amount of leaves at one time.	4
9	The appliance	is easy to clean	4
10	The appliance	is safe to use.	5
11	The appliance	is easy to use without the need of a lot of instruction	3
12	The appliance	uses resources efficiently.	4
13	The blade	is sharp enough to slice eru.	5
14	The blade	is durable.	4
15	The blades	have adjustable spacing.	4
16	The shell	is durable and strong enough for travel.	4

Table B3. Bitter leaf washer customer needs.

Need Number	Part	Need	Importance
1	The appliance	is cheap.	5
2	The appliance	reduces the amount of time needed to wash the leaf.	5
3	The appliance	reduces the force and focus needed to wash the leaf.	5
4	The appliance	is rugged enough to go through several wash cycles.	5
5	The appliance	is small so it doesn't take up too much space in the kitchen.	4
6	The appliance	is light enough to be able to be moved around the kitchen.	4
7	The appliance	is easy to build (so people in South Cameroon can recreate it).	3
8	The appliance	uses water and other resources efficiently.	4
9	The appliance	is easy to clean	4
10	The appliance	is water resistant	5
11	Chemical reactant	is basic to reduce acidity.	5

Appendix C Budget

Table C1. Bill of Materials

Project Bill of Materials (Updated Winter 2022)
Project Name: **Victoria Relief Project: Kitchen Appliances for Women in Southern Cameroon**
Date: 1/19/2022

Item Name	Part Number	Description	Units	Cost Per Unit	Budgeted Cost
Building					
Iodized Table Salt	B07RCK4WFT	26 oz	1	$10.00	$10.00
Edible Potash - Limestone	B07CKR9LH6	4oz bag	3	$11.00	$33.00
Crank Handle	MV-M-130-P6-ST	5.12" arm	4	$30.00	$120.00
Bicycle Handle Grips	B097XZTQ9W	Rubber grips (5.43" x 4.38" x 1.46")	4	$6.00	$24.00
Bicycle Chain	B097SNNZQF	Chain used to connect gearing	4	$20.00	$80.00
Bike Crank Arm	B08NHHCHTD	Gear and crank	4	$50.00	$200.00
Chainring Gears (assorted sizes)		Gears in different sizes and teeth number	5	$15.00	$75.00
Plastics					
3-D Printing Plastic - ABS	3D ABS-1KG1.75-BLK	1kg spool, 1.75mm filament diameter, 2.20" hole diameter	3	$25.00	$75.00
Acrylic Sheets		1/8" thick sheets (set of 4)	1	$120.00	$120.00
Metals					
Stainless Steel Sheet	8983K373	Multipurpose 304 Stainless Steel Sheet, 12" x 24", 1/2" Thick	2	$291.42	$582.84
Blades					
Stainless Steel Blades	58920	3/8" stainless steel (pack of 16)	1	$60.00	$60.00
Sandpaper					
Water-Resistant Sanding Rolls - Grit 320	8225A78	Extra-Smooth Finish, 2-1/2" Wide, Grit 320, Length 30 ft.	1	$35.32	$35.32
Water-Resistant Sanding Rolls - Grit 240	8225A79	Extra-Smooth Finish, 2-1/2" Wide, Grit 240, Length 30 ft.	1	$35.32	$35.32
Water-Resistant Sanding Rolls - Grit 80	8225A86	Extra-Smooth Finish, 2-1/2" Wide, Grit 80, Length 30 ft.	1	$35.32	$35.32
Testing					
VeggiChop	102-239-011	Chef'n VeggiChop Food Chopper	1	$25.00	$25.00
Slap Chop	COMINHKPR119445	Slap Chop Slicer with Stainless Steel Blades	1	$30.00	$30.00
Salad Spinner	32480	OXO Good Grips Salad Spinner (6.22Qt)	1	$35.00	$35.00
Eru Leaf		10lb Eru Leaf	2	$20.00	$40.00
Bitter Leaf		10lb Bitter Leaf	2	$20.00	$40.00
Wood Slabs		4" wide, 1" thick, 6ft long	1	$10.00	$10.00
5 gal Bucket	005GFNAT020	5 gallon, BPA free bucket	3	$10	$30.00
2 gal Bucket		2 Gallon Food Grade Bucket with Easy Airtight Spin Off and Spin On Gamma Seal Lid Bundle - Lid Has Been Installed to the Bucket	3	$25	$75.00
Two-Grit Sharpening Stones	6160A45	8" Long x 2" Wide x 1/2" Thick, 400 and 800 Grit	1	$90.70	$90.70

PPE					
Cut Resistant Gloves	S-19248	FDA standards for food contact, Cut level A6, Abrasion level 4	10	$30.00	$300.00
Safety Glasses	S-21076	Anti-fog, wrap around safety glasses	10	$5.00	$50.00
Face Shields	S-12571	Propionate shield protection from chemical splash	5	$15.00	$75.00
First Aid Kit	H-1292	Assorted bandages, antiseptic, gauze, pads, gloves, etc	1	$25.00	$25.00
Burn Kit	H-4172	Burn dressings, gels, instant cold compress, non-stick pads	1	$50.00	$50.00
Light Duty Paper Wipes	7036T11		2	$7.00	$14.00
Budget Total					**$2,375.50**

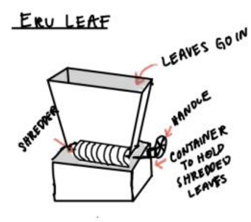
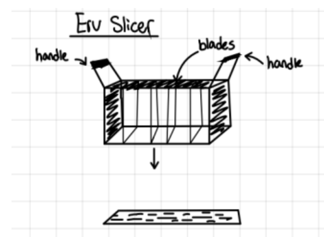
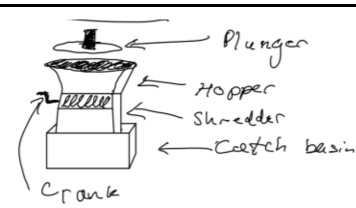
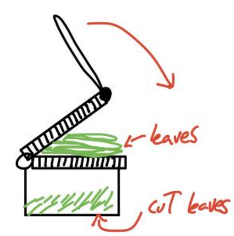
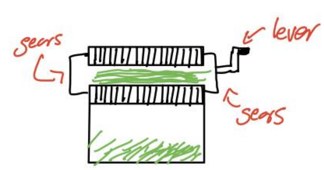
Appendix D Risk Assessment

Table D1. Risk assessment.

Severity of Risk	1- Very unlikely	2- Feasible	3- Likely	4 - Very Likely
4 - Extremely High: ex: fatal	4	6	7	8
3 - High Ex: Life altering injuries	3	5 Cutting fingers/hands with sharp or dull blades Centrifugal forces (spinning) catching onto something Gears catching onto something	6	7
2 - Moderate Ex: Small injuries or setback	2 Food poisoning	4 Carrying Heavy Material Assembling and handling blades	5 Water rusting	6
1 - Minor Ex: No injuries or setbacks, very small and rare cuts	1	3	4	4

Appendix E Concept Sketches

Table E1. Eru leaf Shredder concept sketches.

No.	Description	Sketch
A	Leaves are inserted into the top section of the appliance. From there, the leaves go through a shredder that may be controlled by a handle on the outside. The shredded leaves then fall into a holder.	
B	A series of blades are inserted into a plastic housing. The blades can be removed and placed into a number of slots to adjust spacing. The user holds each handle and presses the appliance down onto the eru leaves to slice.	
C	A paper shredder-esque design as a series of fine blades overlap and rotate with one another as the crank is used. A plunger will help push the leaf into the shredder through the feeding hopper and will fall into the catch basin.	
D	The leaves are put between two opposing sections of blades. One section may be pulled through the other section of blades using the handle.	
E	Similar to the previous design, the leaves are put between the opposing sections of blades. One section may rotate through the other section using a lever.	

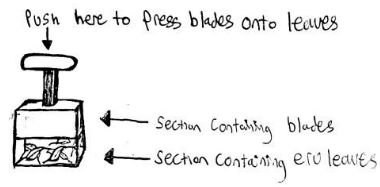
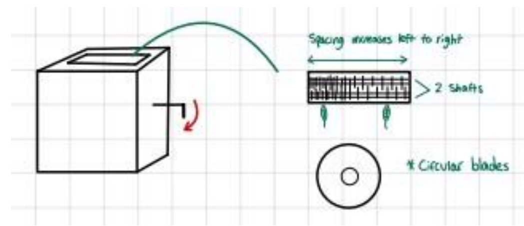
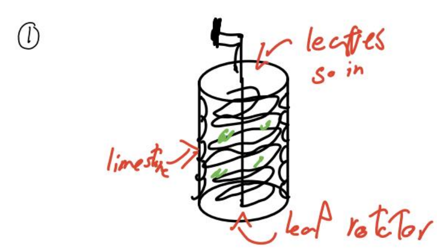
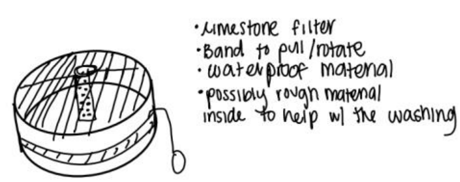
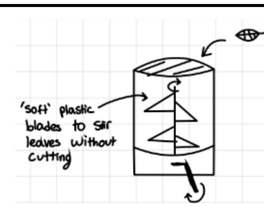
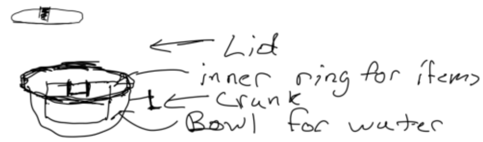
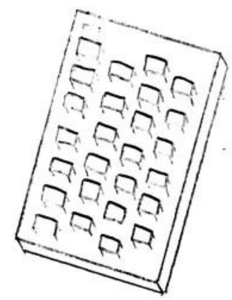
F	Blades are arranged in the top section of the device. The leaves may be cut by pushing down the top section of blades onto the bottom section.	
G	Two shafts with a series of blades are arranged inside an opening on top of the housing (much like a paper shredder). The housing can be made from plastic or ceramic. The user feeds in leaves while turning a handle on the side of the housing to rotate the blades and slice eru. The blades are spaced closely together on one side of the opening and further apart on the other for adjustability in slice size.	

Table E2. Bitter leaf washer concept sketches.

No.	Description	Sketch
A	Leaves feed into the top of the appliance. They are rotated using the handle through limestone brushes that work to clean the leaves. The material is mesh in order to filter the water and leaves.	
B	Similar to the last design, the band works to rotate the inside of the appliance. The inside material is rough to assist in the washing process. There is also a limestone filter. Leaves are put in through the top and filtered/washed.	
C	A rotating handle is connected to a shaft through the center of the plastic housing. To operate, the user drops leaves and water in through the top then rotates the handle to spin the shaft. Attached to the shaft are plastic blades which stir the leaves in the water to remove their bitterness.	

D	An inner perforated bowl that is able to be a centrifuge like spinning in an outer bowl of water at the use of a manual crank. A small insert catch could be used to add limestone to help reduce bitterness.	
E	The device is a plastic washboard that has teeth that the leaves may be pressed into. Water may run from the top and run through the teeth, simultaneously cleaning the leaves.	

Appendix F Concept Selection Tables

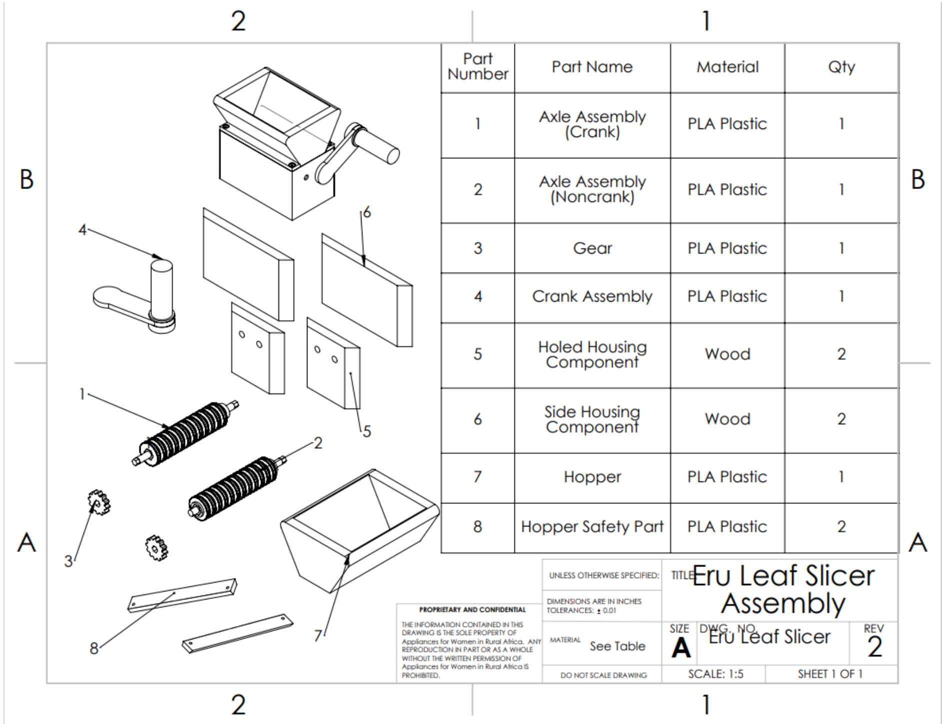
Eru Leaf Slicer			Concepts															
			A		B		C		D		E		F		G		G + A	
Selection Criteria	**Specification**	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	< $10	20%	4	0.8	6	1.2	4	0.8	5	1	4	0.8	8	1.6	6	1.2	6	1.2
Time	< 2 min	20%	9	1.8	4	0.8	9	1.8	8	1.6	6	1.2	6	1.2	7	1.4	9	1.8
Physical Exertion	N	10%	9	0.9	6	0.6	9	0.9	7	0.7	5	0.5	4	0.4	9	0.9	9	0.9
Safety	Blade to Hand Distance (mm)	10%	7	0.7	5	0.5	7	0.7	8	0.8	8	0.8	9	0.9	7	0.7	8	0.8
Portability	< 5 lbs & < 1 cubic ft	5%	6	0.3	10	0.5	4	0.2	3	0.15	5	0.25	7	0.35	5	0.25	5	0.25
Durability	> 700 Mpa	10%	7	0.35	7	0.35	7	0.35	6	0.3	6	0.3	6	0.3	7	0.7	7	0.7
Ease of Cleaning	Number of Steps	5%	2	0.2	8	0.8	2	0.2	4	0.4	3	0.3	4	0.4	2	0.1	2	0.1
Ease to Build	# of parts	20%	3	0.15	9	0.45	3	0.15	6	0.3	4	0.2	7	0.35	4	0.8	4	0.8
		Total Score	5.2		5.2		5.1		5.25		4.35		5.5		6.05		6.55	
		Rank	5		5		7		4		8		3		2		1	
		Continue?	No		No		No		No		No		No		No		Yes	

Figure F1. Eru leaf shredder concept selection table.

Bitter Leaf Washer			Concepts											
			A		B		C		D		E		A + C	
Selection Criteria	**Specification**	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	< $10	20%	6	1.2	5	1	7	1.4	6	1.2	9	1.8	7	1.4
Time	< 2 min	25%	9	2.25	9	2.25	9	2.25	9	2.25	2	0.5	9	2.25
Ease of Use	N	15%	7	1.05	8	1.2	8	1.2	8	1.2	5	0.75	8	1.2
Safety	Probability of injury	5%	8	0.4	9	0.45	9	0.45	10	0.5	10	0.5	10	0.5
Portability	< 5 lbs & < 1 cubic ft	5%	6	0.3	7	0.35	6	0.3	6	0.3	10	0.5	6	0.3
Durability	> 700 Mpa	10%	8	0.4	6	0.3	8	0.4	8	0.4	9	0.45	8	0.4
Ease of Cleaning	Number of Steps	5%	7	0.7	7	0.7	7	0.7	7	0.7	10	1	7	0.7
Ease to Build	# of parts	15%	6	0.3	5	0.25	5	0.25	6	0.3	10	0.5	5	0.25
		Total Score	6.6		6.5		6.95		6.85		6		7	
		Rank	4		5		2		3		6		1	
		Continue?	No		No		No		No		No		Yes	

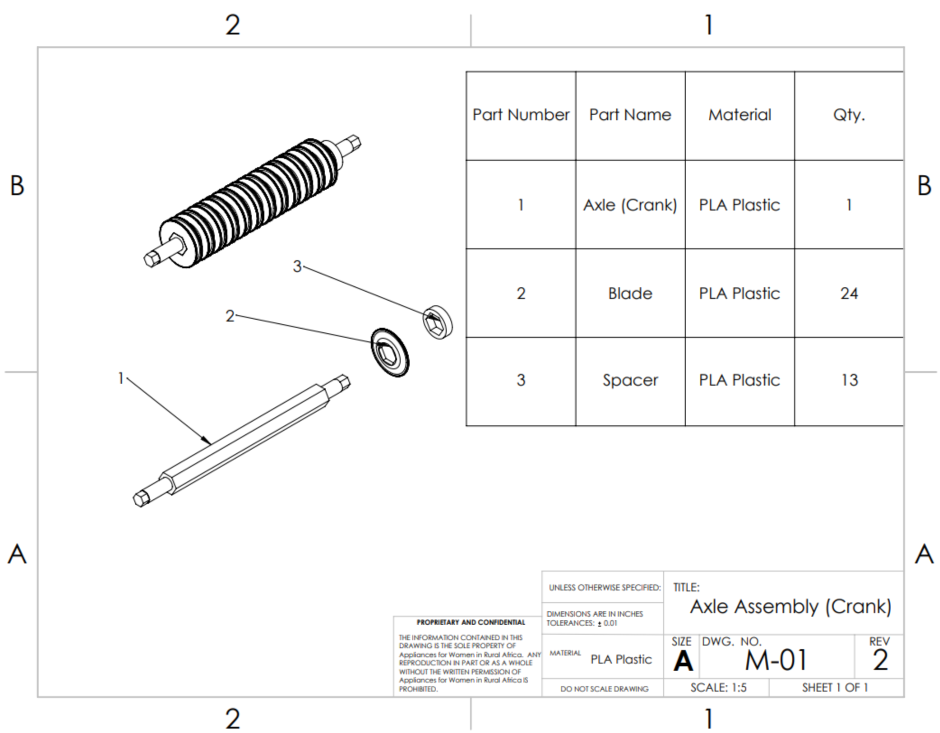
Figure F2. Bitter leaf washer concept selection table.

Appendix G Eru Leaf Shredder Drawings



Part Number	Part Name	Material	Qty
1	Axle Assembly (Crank)	PLA Plastic	1
2	Axle Assembly (Noncrank)	PLA Plastic	1
3	Gear	PLA Plastic	1
4	Crank Assembly	PLA Plastic	1
5	Holed Housing Component	Wood	2
6	Side Housing Component	Wood	2
7	Hopper	PLA Plastic	1
8	Hopper Safety Part	PLA Plastic	2

Figure G1. Eru Leaf Shredder Assembly



Part Number	Part Name	Material	Qty.
1	Axle (Crank)	PLA Plastic	1
2	Blade	PLA Plastic	24
3	Spacer	PLA Plastic	13

Figure G2. Axle Assembly (Crank)

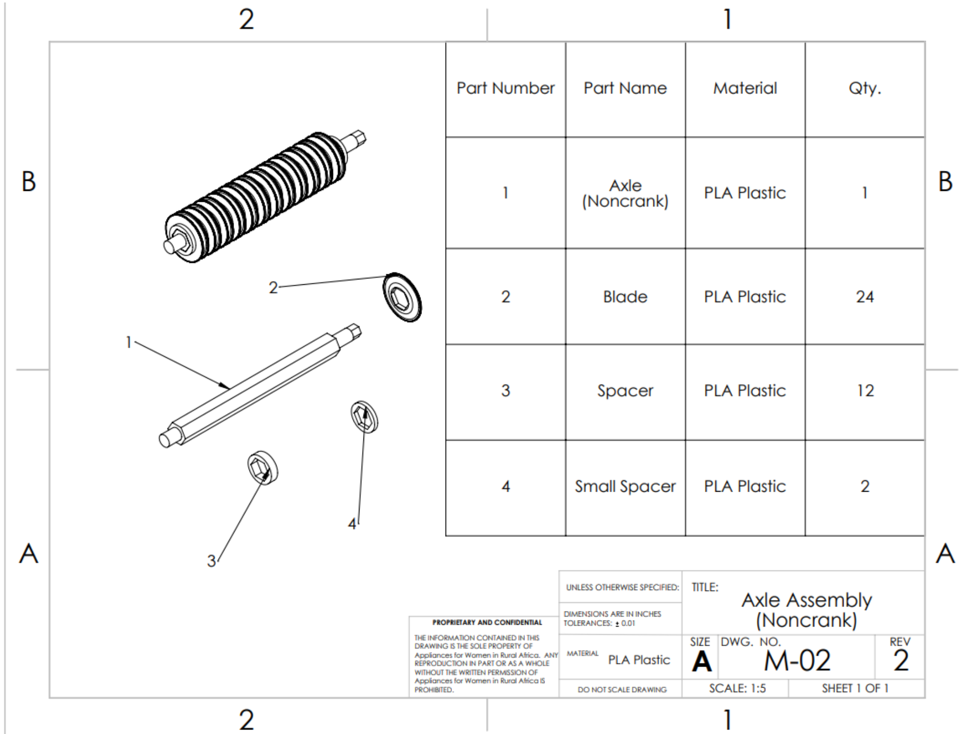


Figure G3. Axle Assembly (Noncrank)

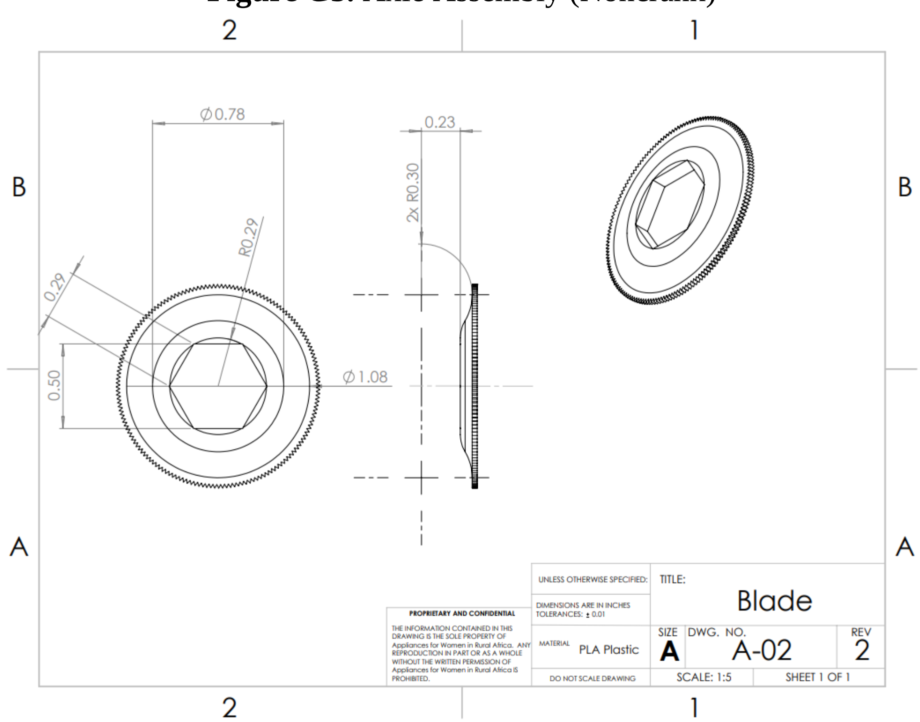


Figure G4. Blade

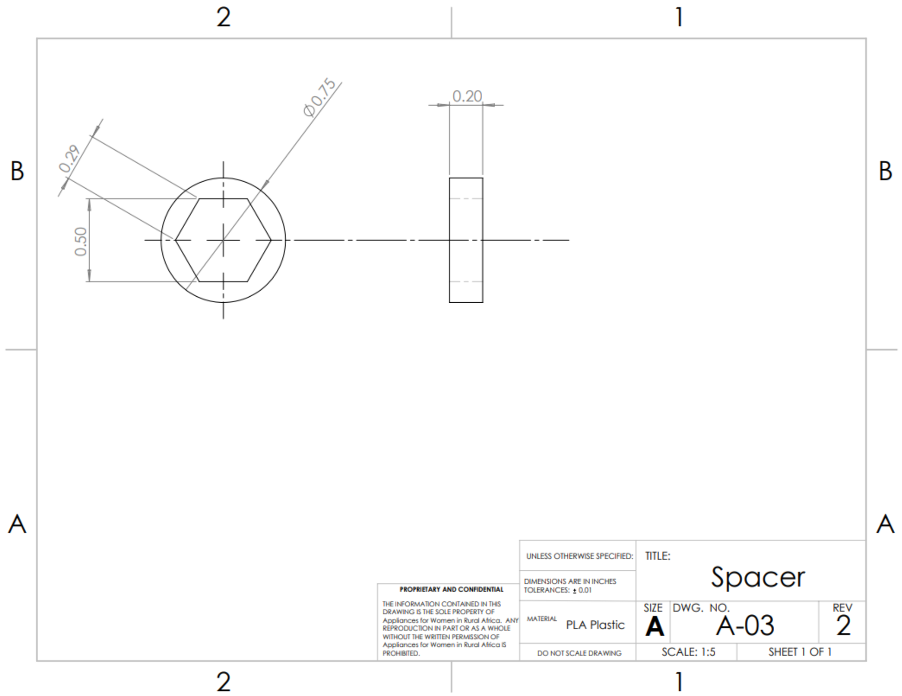


Figure G5. Spacer

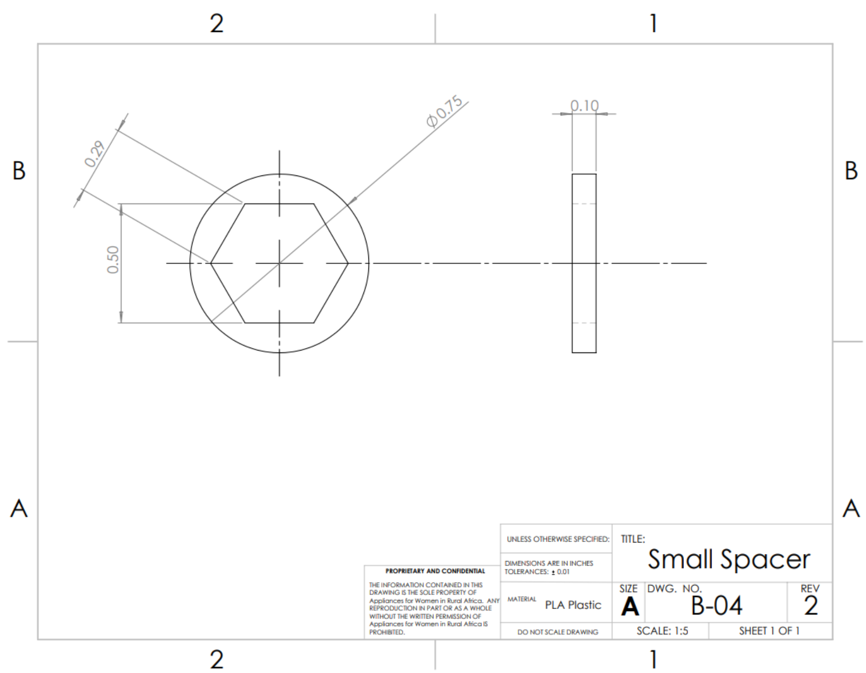


Figure G6. Small Spacer

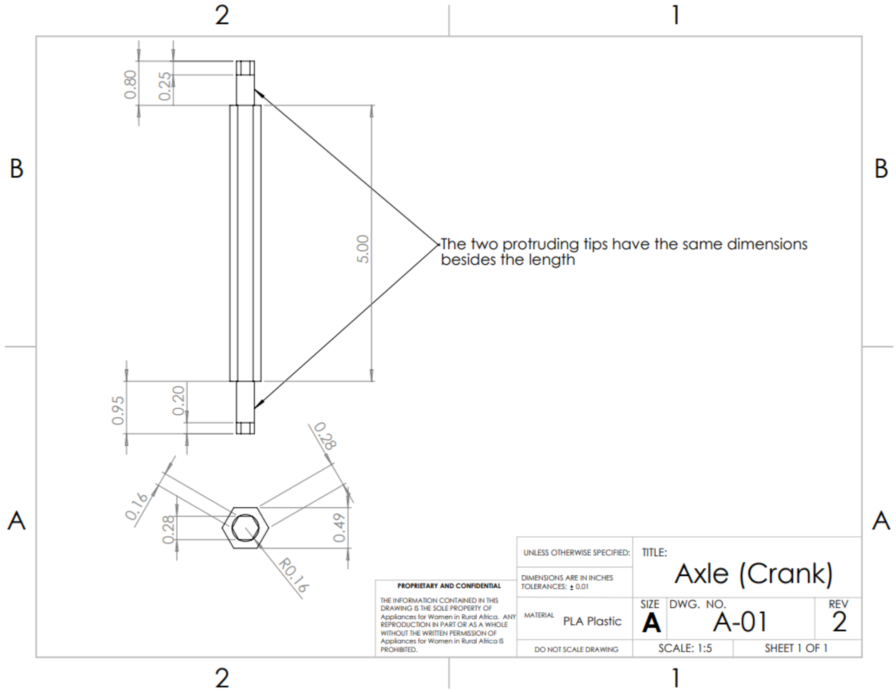


Figure G7. Axle (Crank)

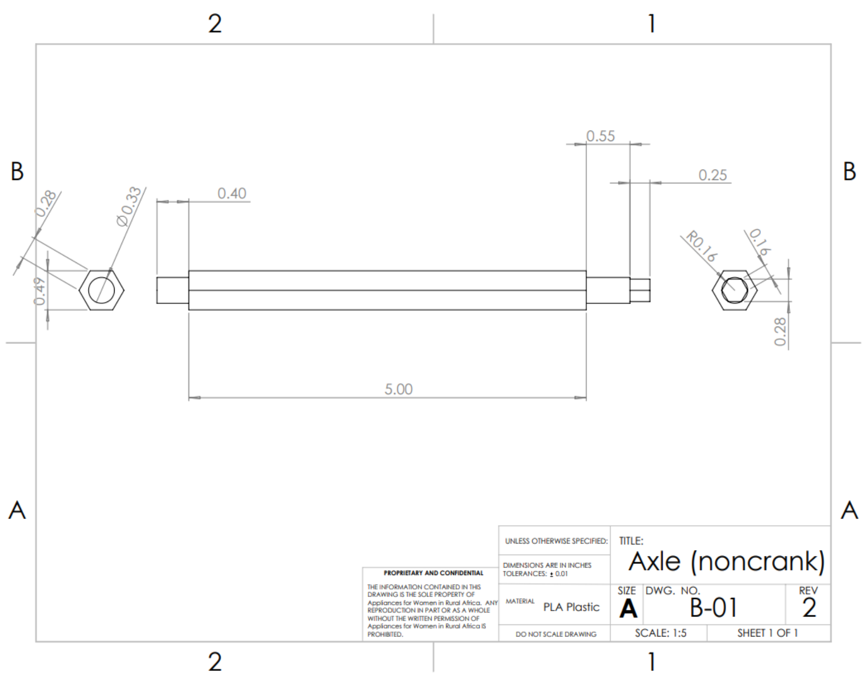


Figure G8. Axle (noncrank)

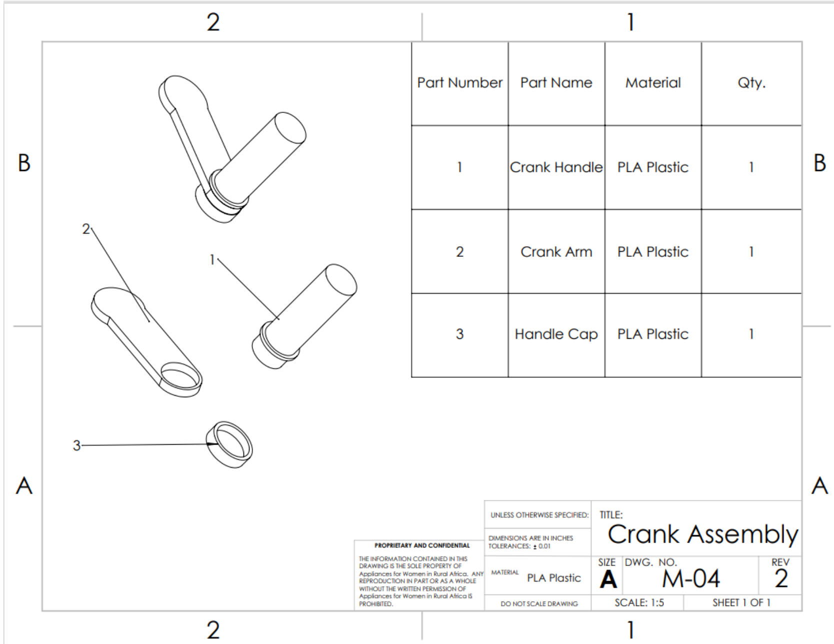


Figure G9. Crank Assembly

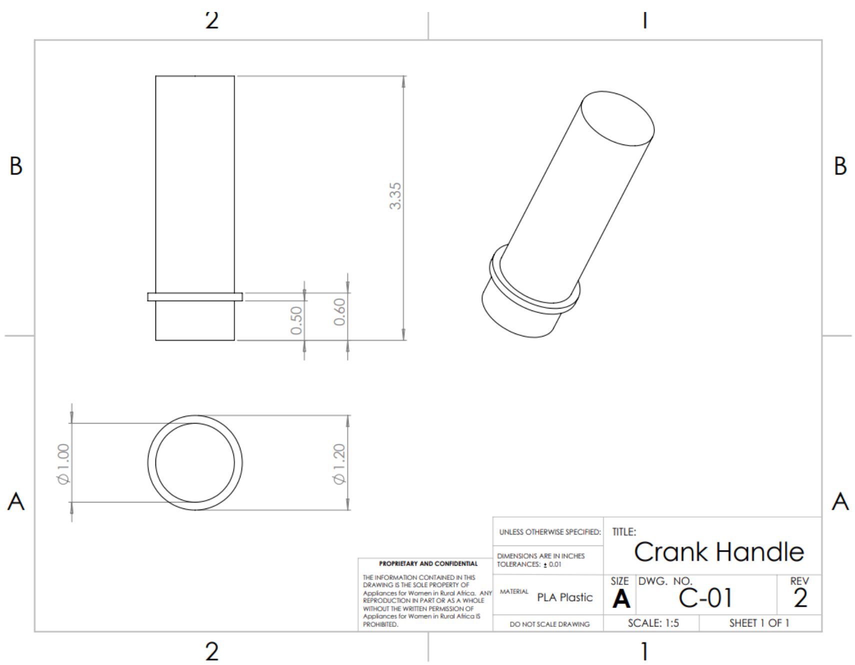


Figure G10. Crank Handle

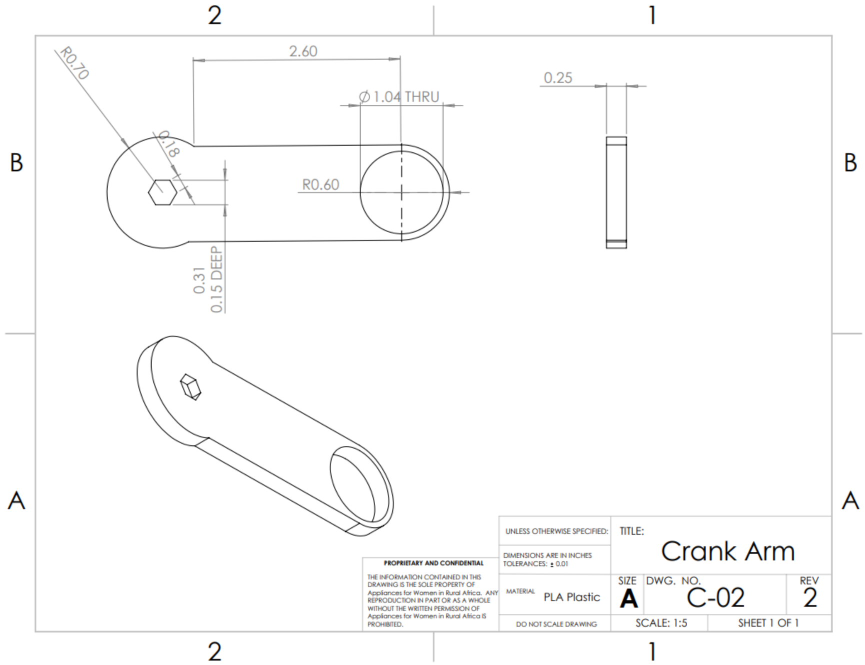


Figure G11. Crank Arm

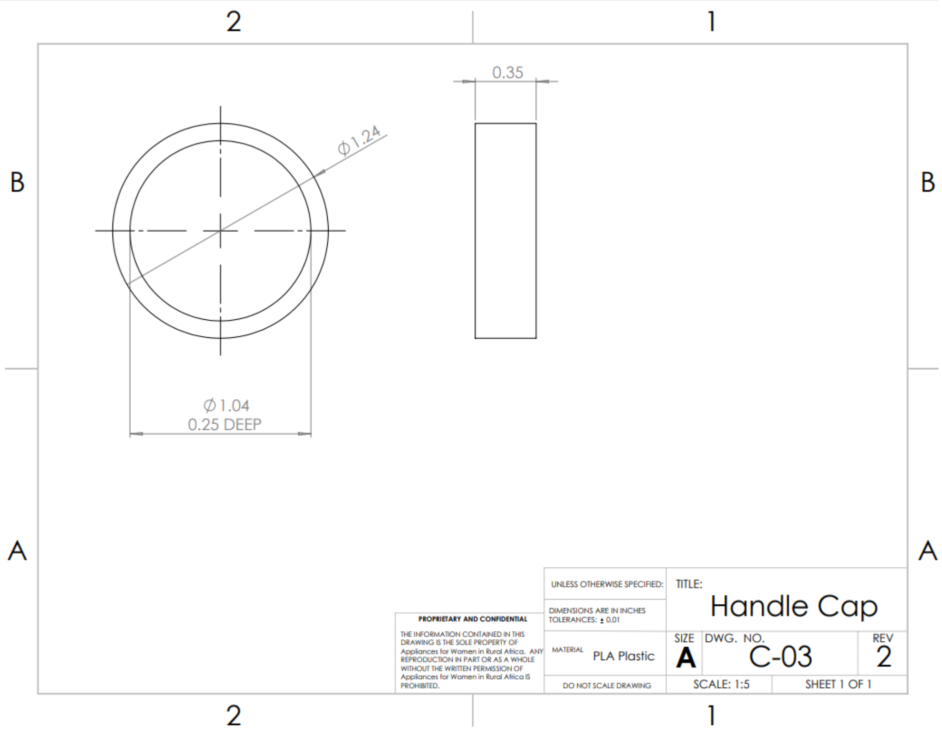


Figure G12. Handle Cap

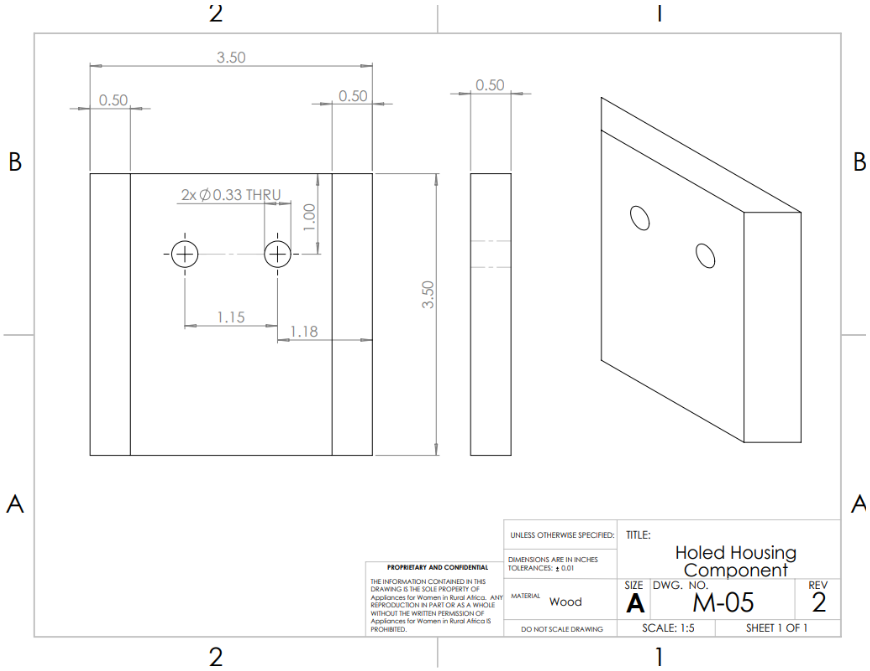


Figure G13. Holed Housing Component

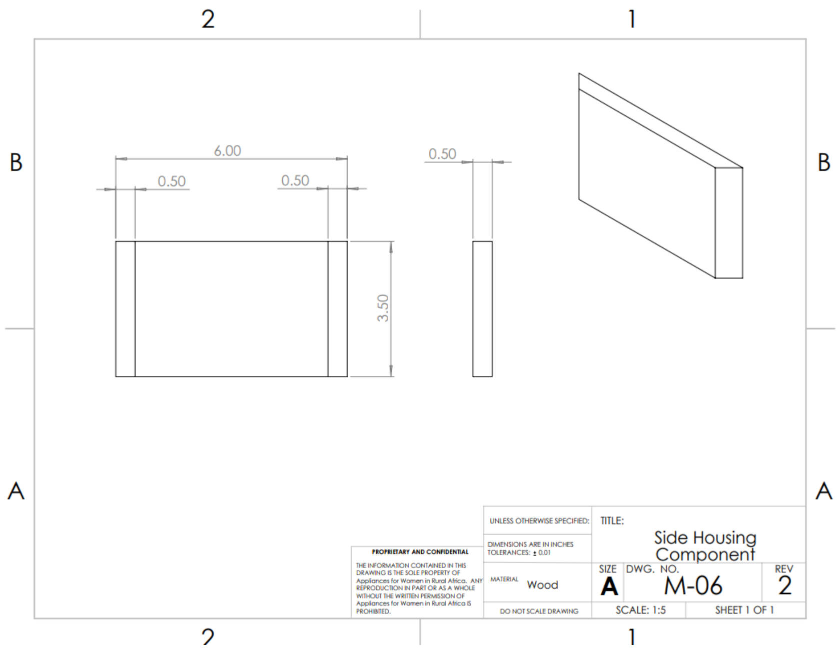


Figure G14. Side Housing Component

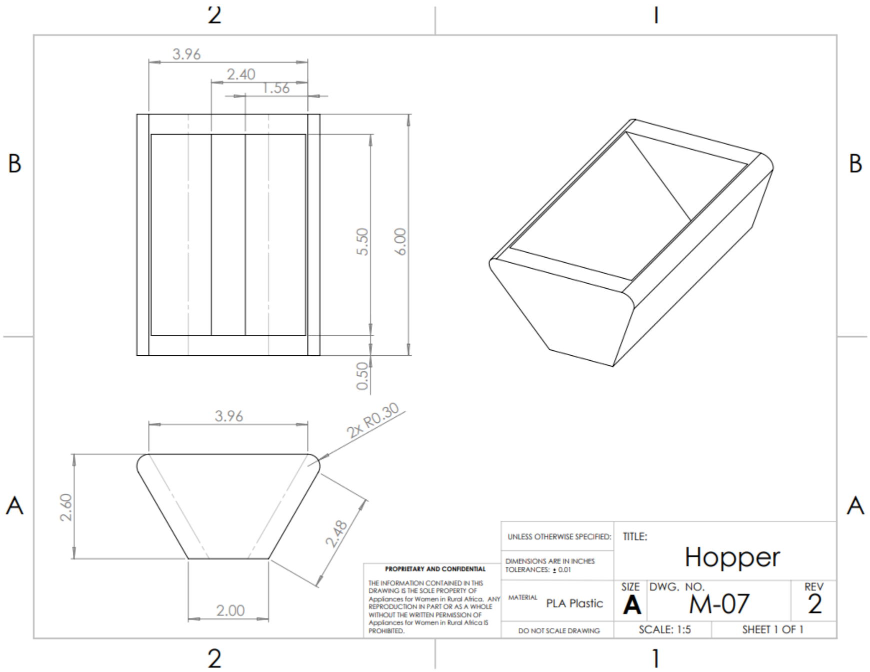
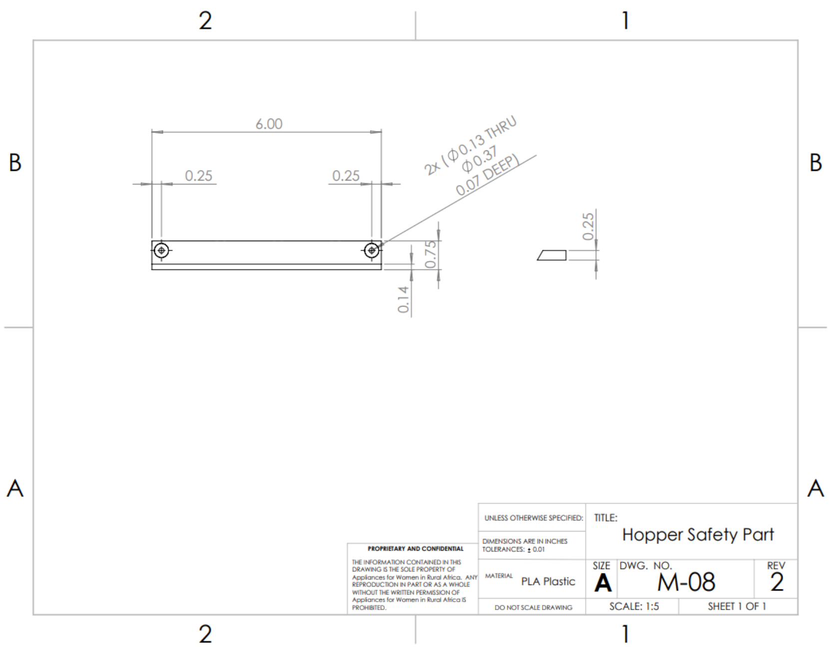


Figure G15. Hopper



FigureG16. Hopper Safety Part

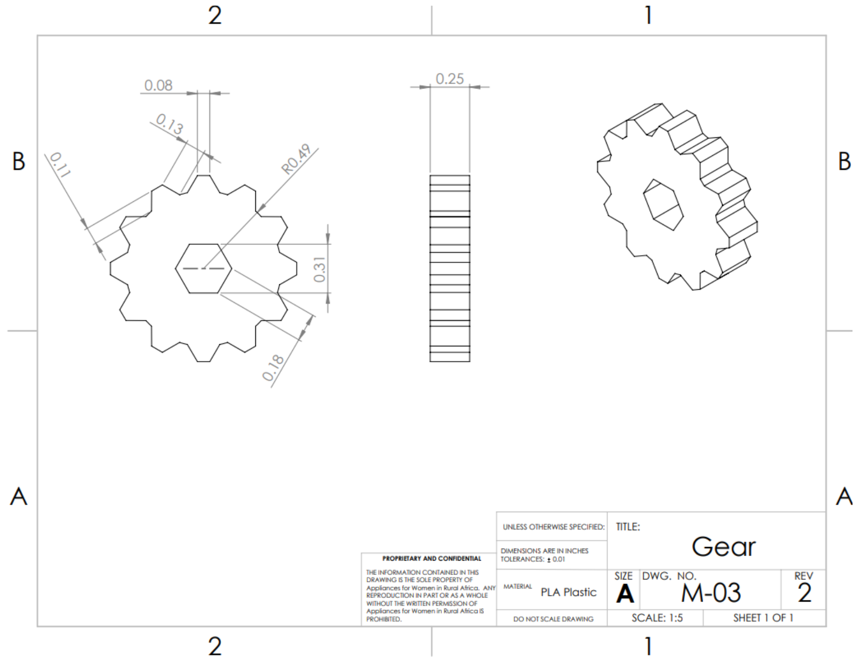


Figure G17. Gear

Appendix H Eru Leaf Shredder Assembly Manual

This manual serves as a guide for how to assemble the eru leaf shredder and bitter leaf washer devices. It is helpful as documentation for how to properly assemble the devices in a time efficient manner.

The following materials are necessary for assembly:

- Wood Glue

The following is a list of parts:

- 2 axles (one with two hexagonal tips and one with a cylindrical tip and hexagonal tip)
- 48 blades
- 25 spacers
- 2 smaller sized spacers
- 1 crank handle
- 1 crank arm
- 1 handle cap
- 2 gears
- 4 housing component pieces (2 of the pieces should be holed)
- 2 hopper safety parts
- 1 hopper

I1. Eru Leaf Shredder Steps to Assemble

Step 1:

Take the axle with 2 hexagonal tips. Position the axle so that the longer hexagonal tip is on your right hand side. Proceed to slide a blade towards the right end of the axle.

It should reach the end. The side that is rounded outwards should face away from the right end of the axle.

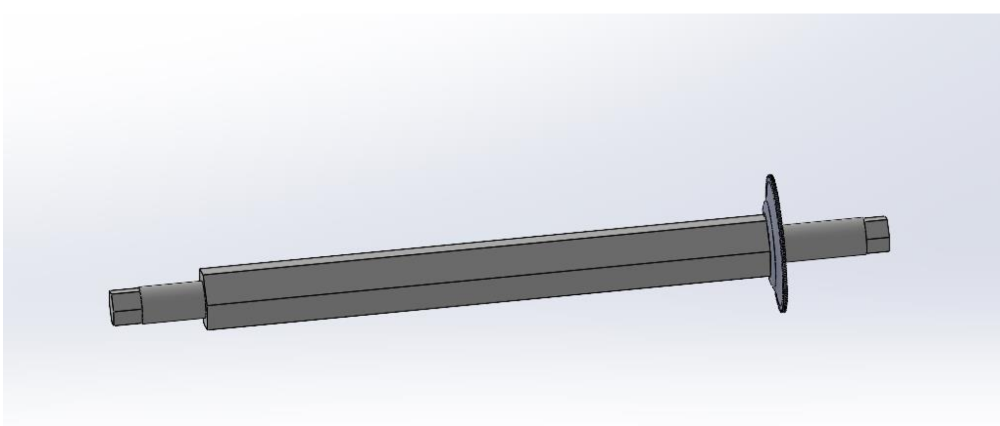


Figure H1. Hexagonal tipped axle with a single blade.

Step 2:

Take another blade and slide it onto the axle next to the blade at the end. The side that is rounded outwards should face towards the blade from part 1. The rounded parts of the blades should be touching.

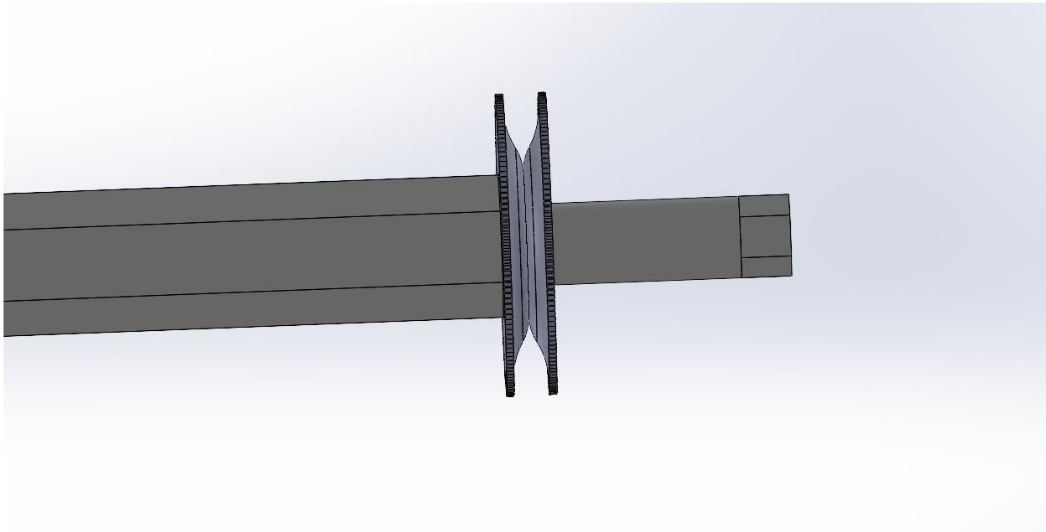


Figure H2. Axle piece with two blades attached with proper positioning.

Step 3:

Slide on a regular sized spacer until it touches the flat side of the blade.

Step 4:

Repeat steps 1 through 3 until using 24 blades. After placing the last spacer, there should be 12 on this axle. Place another spacer so that there are two spacers touching on the left end.

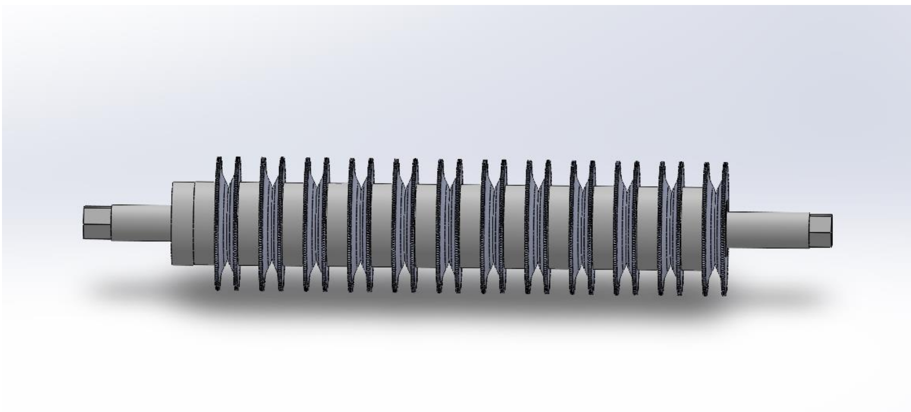


Figure H3. Completed first axle.

Step 5:

Position the other axle such that the cylindrical tip is on your right hand side.

Slide one smaller spacer down to the right end of the axle and then complete the same assembly process as the other axle, using up the remaining 12 blades and 12 normal sized spacers.

Once completed, slide the remaining smaller spacer on the axle, which should now be touching the last normal sized spacer that was placed.

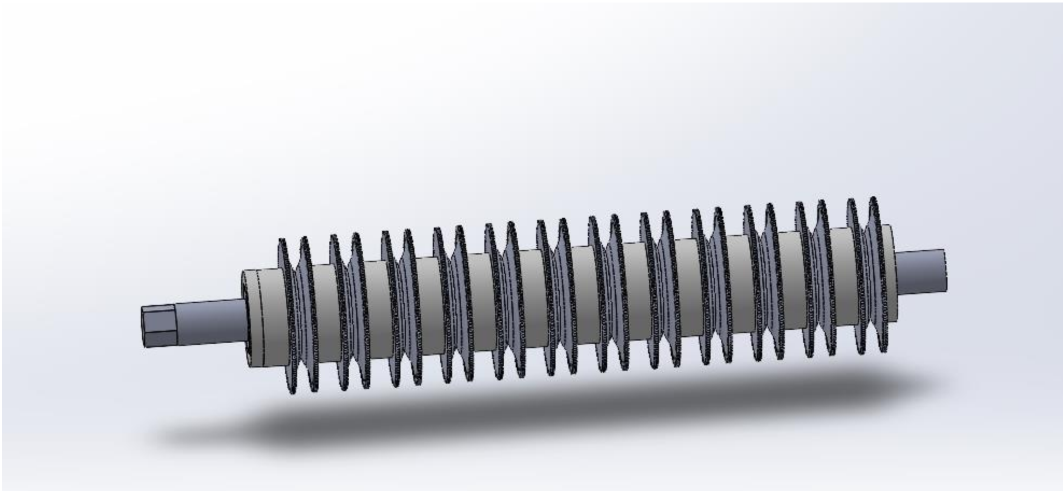


Figure H4. Second completed axle.

Step 6:

With the two axles completed, place the right ends of both axles through the holes of one of the holed housing component parts. The axle with the smaller cylindrical tip should be in the hole nearest to yourself.

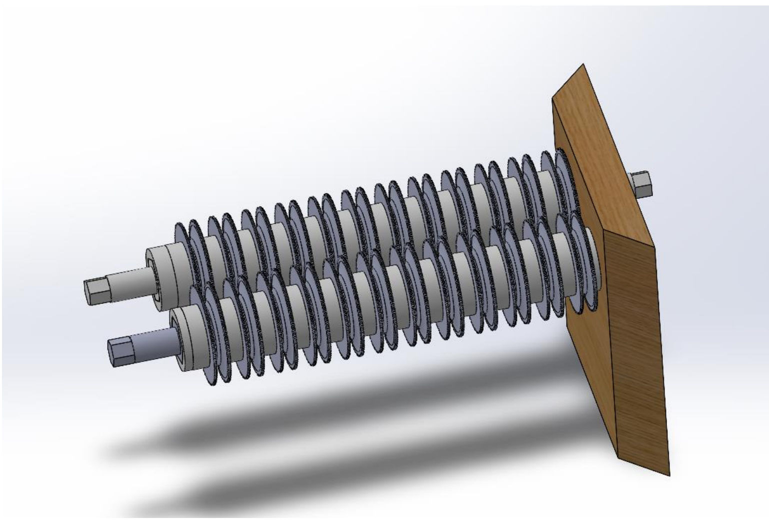


Figure H5. Axles connected properly to holed housing component.

Step 7:

Place the other ends of the axles through the holes of the other holed housing component part.

Step 8:

Using your adhesive. take the other two, longer, housing component parts and connect the edges from each part to the edges of the part assembled in step 7. The assembled parts should fit together in the shape of a box.

Figure H6. Constructed housing components.

Step 9:

The axle furthest away should have two protruding hexagonal tips. On the right side of this axle, attach the crank arm by lining up the hexagons.

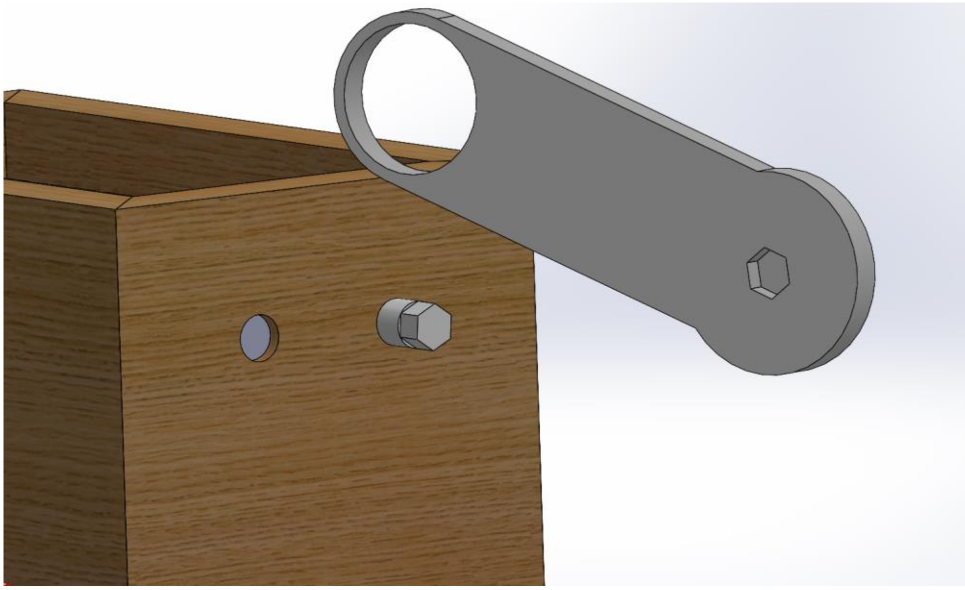


Figure H7. Displaying the two hexagons that should be connect.

Step 10:
Slide the short part of the crank handle through the hole in the crank arm, towards the axles. And then place on the handle cap on the left hand side of the crank handle, which should now be connected with the crank arm.

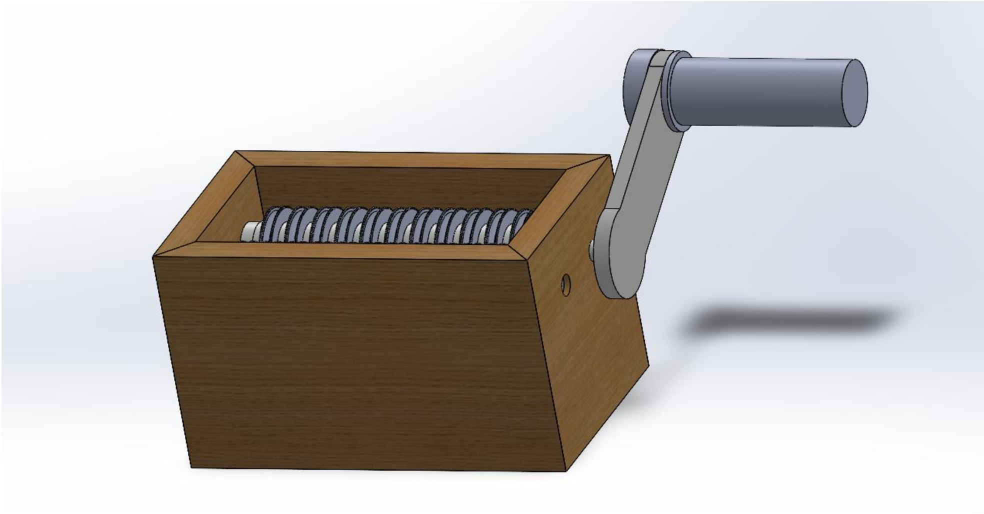


Figure H8. Fully constructed hand crank.

Step 11:

On the left side of the box created in step 8, slide on the gears by connecting the hexagons, such that the gear teeth fit in between each other.

Step 12:

Using your chosen adhesive, connect the hopper safety parts to the top of the box. The fileted edges should face inward, and pieces should fit on the edges of the side housing component pieces.

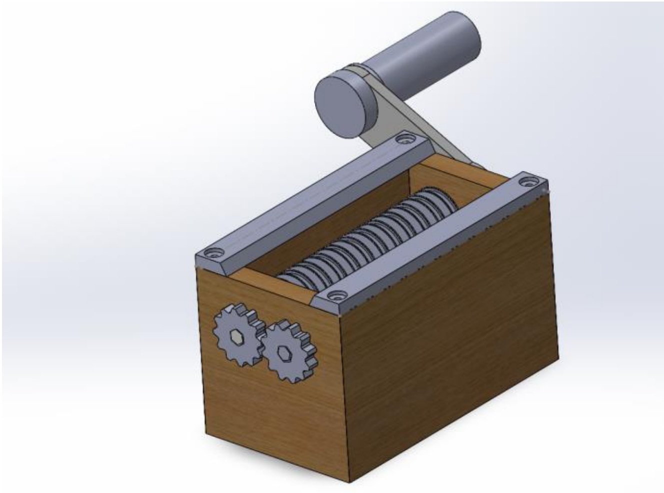


Figure H9. Connected hopper safety parts.

Step 13:

Using your chosen adhesive, connect the hopper to the top of the box and between the two hopper safety parts.

The shredder is now completed.

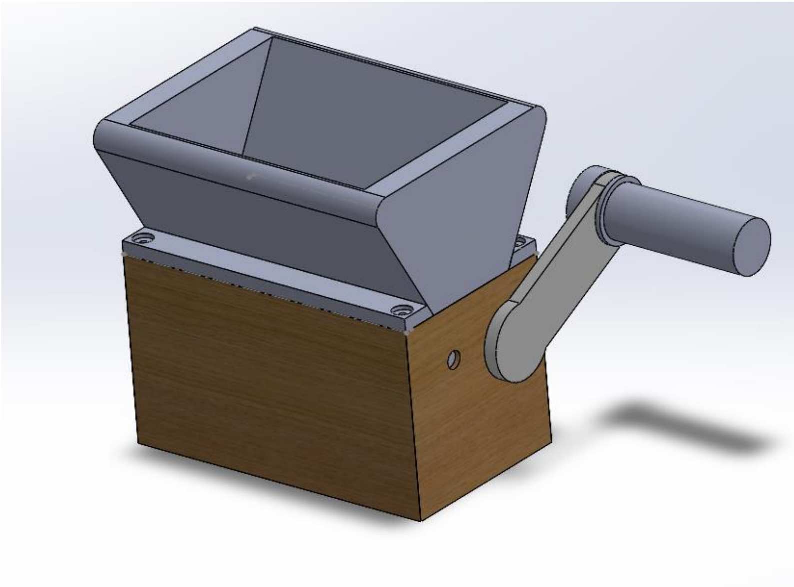


Figure H10. Fully constructed leaf shredder.

Appendix I Bitter Leaf Washer Drawings

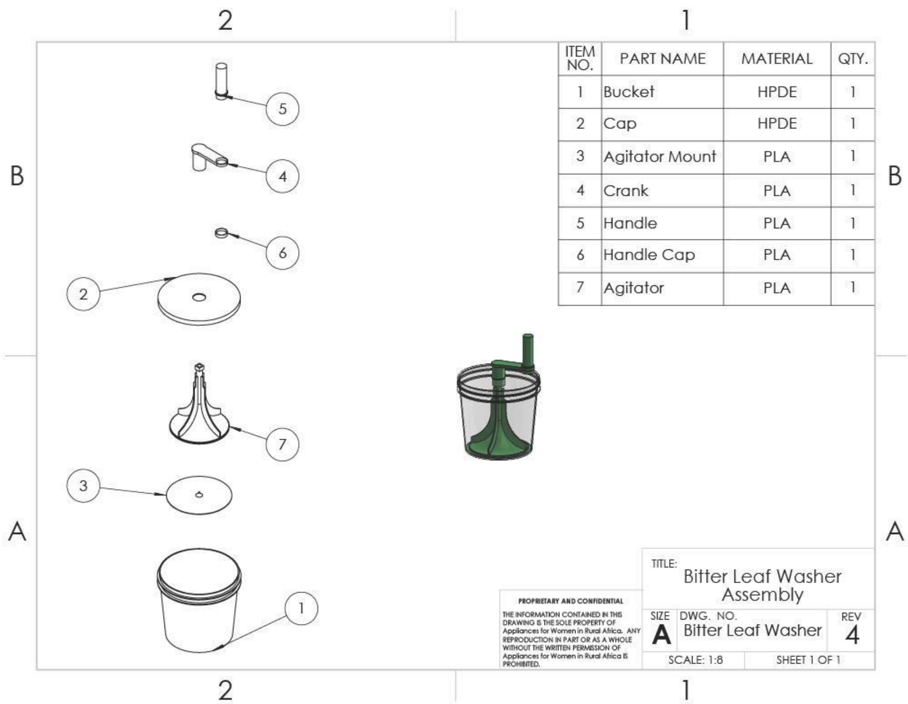


Figure I1. Assembly of Bitter Leaf Washer.

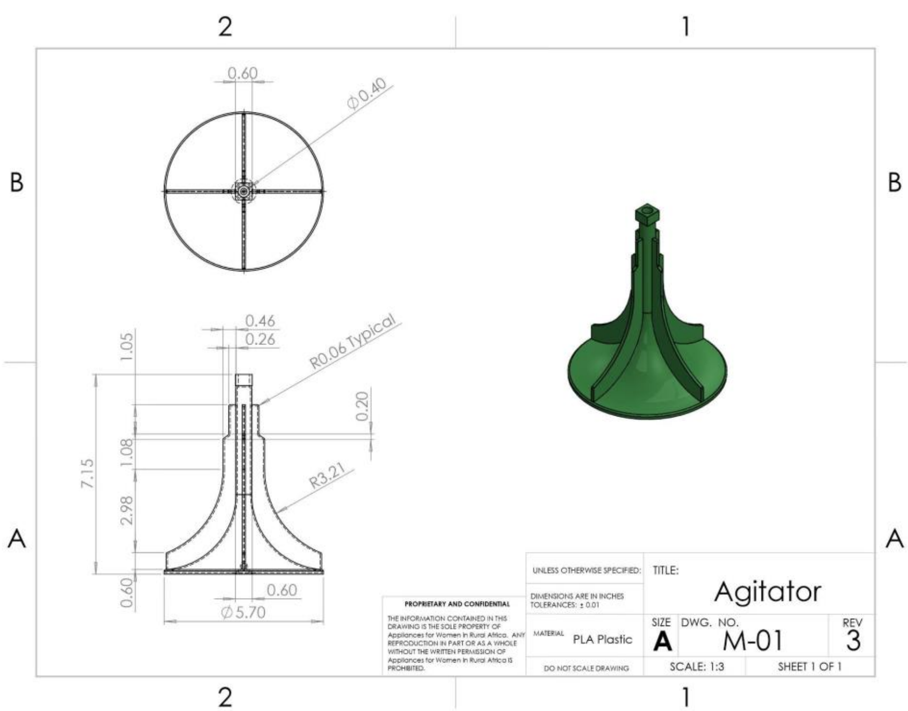


Figure I2. Detailed drawing of agitator.

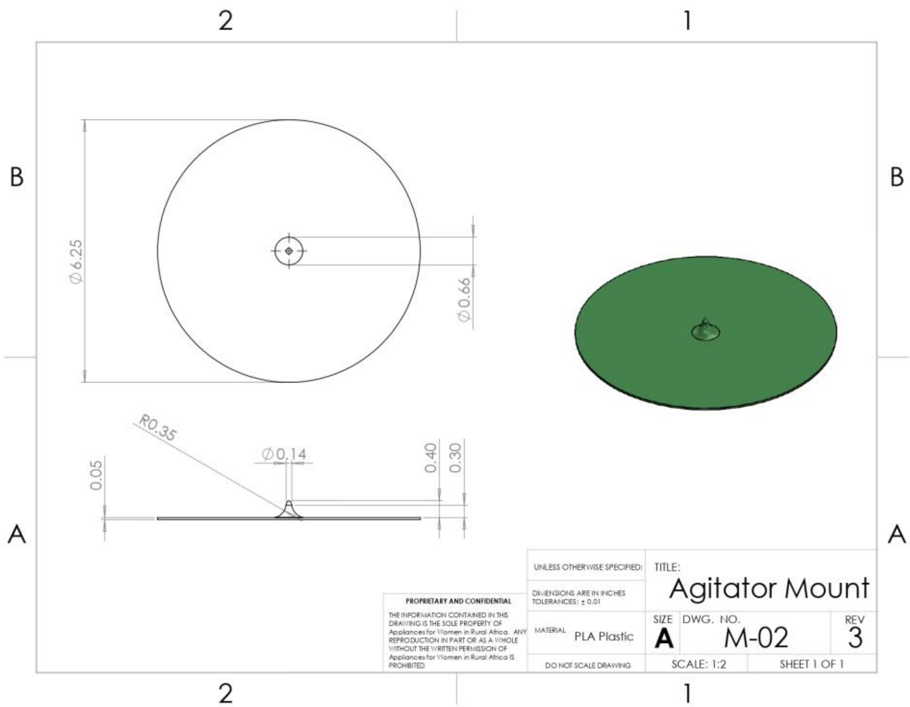


Figure I3. Detailed drawing of agitator mount.

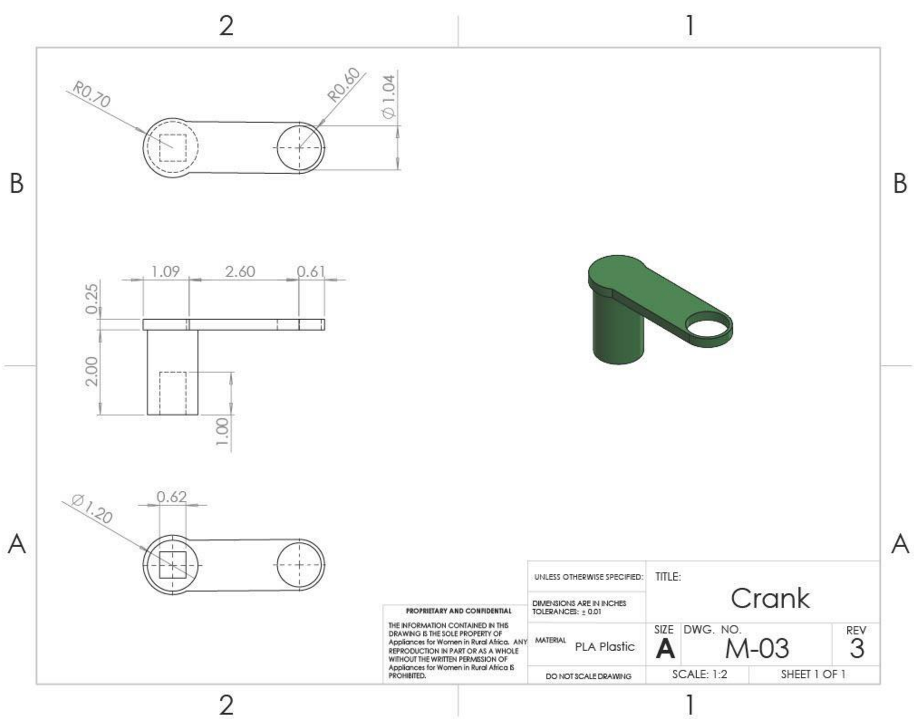


Figure I4. Detailed drawing of crank.

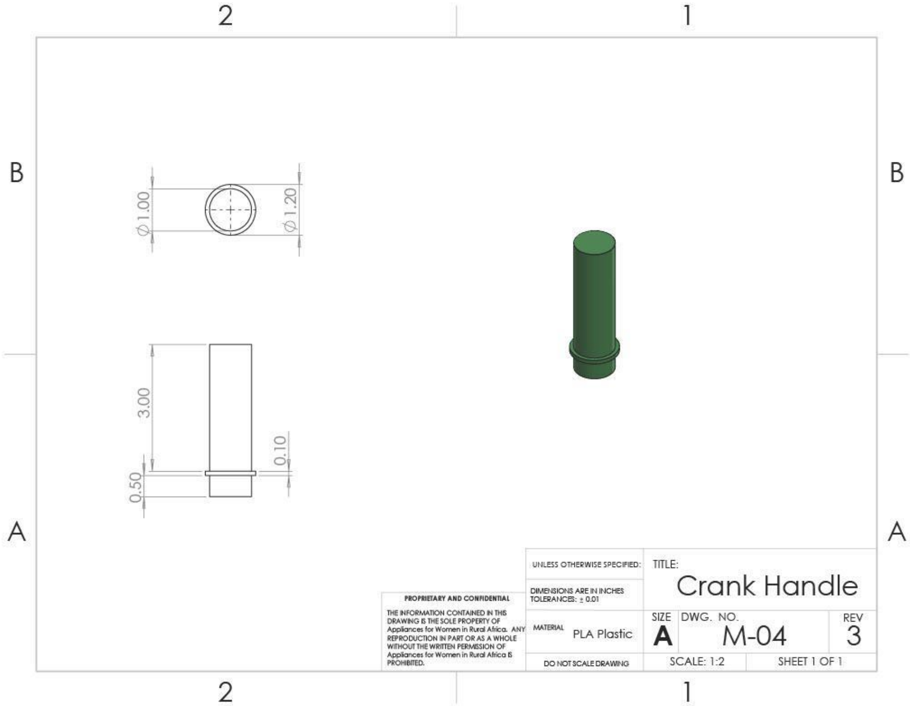


Figure I5. Detailed drawing of crank handle.

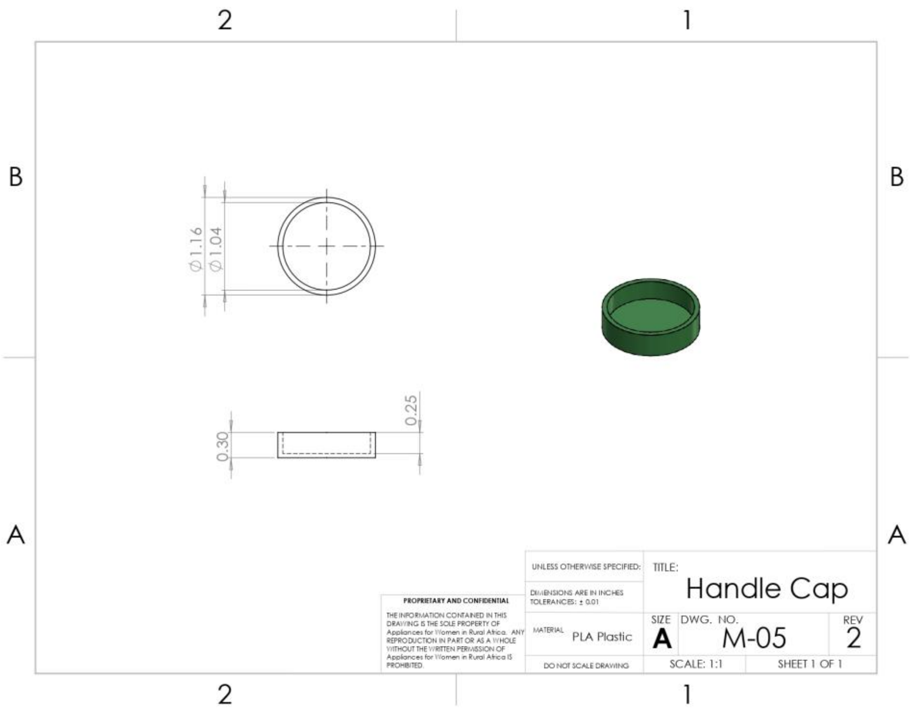


Figure I6. Detailed drawing of handle cap.

Appendix J Bitter Leaf Washer Assembly Manual

This manual serves as a guide for how to assemble the bitter leaf washer. The assembly process is relatively short and does not require a large amount of materials. The following materials are necessary for assembly:

- Blade (preferably a box cutter)
- Hot Glue (or any water proof adhesive for plastic)
- Sharpie

The following is a list of all the required pieces of the Bitter Leaf Washer:

- Bucket
- Lid
- Agitator
- Agitator Mount
- Crank Arm
- Crank Handle
- Handle Cap

J.1 Steps

1. **Assemble the Crank Handle.** Three pieces make up the crank handle assembly: the arm, handle, and cap. Begin by inserting the handle into the hole on the crank arm. Ensure the lip on the handle is on the side opposite to where the assembly connects to the top of the agitator. Next apply hot glue to the inside of the cap and attach this to the bottom part of the handle that is sticking out from the arm.

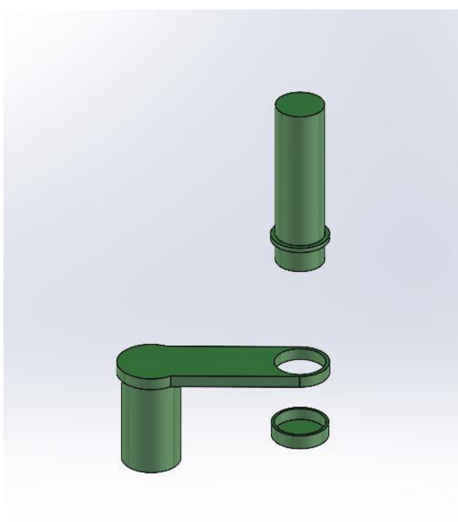


Figure J1. Crank handle assembly exploded view.

2. **Cut the lid hole.** In order for the crank arm to connect to the agitator, there must be a hole in the bucket lid. Place the crank arm on the top of the lid and outline the connector using a sharpie. Cut this hole using a blade in the best circle possible. We want this hole to be relatively snug, start smaller and test fit for adjustments.

Figure J2. Lid with hole cut in the center.

3. **Install the agitator mount.** Apply a generous amount of hot glue to the bottom of the agitator mount. Slide the mount to the bottom of the bucket, press to the surface and allow it to dry.

Figure J3. Bucket with agitator mount fastened to the bottom.

4. **Assemble the remaining components.** The rest of the assembly connects together intuitively. Drop the agitator into the bucket, allowing it to sit on the pin of the mount. Clip the lid to the top of the bucket and attach the crank handle through the lid to the top of the agitator.

Figure J4. Bitter leaf washer agitator (left), bucket (center), handle and lid (right).

Figure J5. Agitator placed on top of mount.

Figure J6. Bitter leaf washer fully assembled.

Appendix K How to Scale Agitator

This manual serves as documentation for how to adjust the scale of the agitator for the Bitter Leaf Washer appliance. It is necessary to adjust the size of the agitator to use it for buckets/containers of different sizes. The original agitator SolidWorks file is set up for a 1 gallon bucket. In addition to changing the scale of the agitator, the diameter of the agitator mount will need to be adjusted to match the size of the bottom of the bucket. Similarly, the original SolidWorks file is set up for a 1 gallon bucket.

If done properly, using the instructions detailed in this documentation, no other parts will need to be modified. The crank handle mount on the top of the agitator and the agitator mount slot on the bottom of the agitator will both remain the correct size.

K.1 Steps

1. **Determine required agitator height.** Measure the inside height of your container. The agitator should be about 0.25 inches less than this height.

2. **Determine scaling factor.** The standard height of the agitator is 7.6 inches and the standard scaling factor is 0.57. To obtain the desired scaling factor, use the following formula with height values in inches:

$$Scaling\ Factor\ =\ 0.57 \times \frac{(inside\ height\ of\ container\ -\ 0.25)}{7.6}$$

3. **Open the SolidWorks file.** Open BL_Agitator SolidWorks part file.

4. **Apply scaling factor.** On the left side of the window you should see the feature manager design tree. Navigate to “Scale 1”, right click, and select the “edit feature” option. A window will open with options to edit the scaling factor. Replace the current value of 0.57 with your new scaling factor. Click the green check mark.

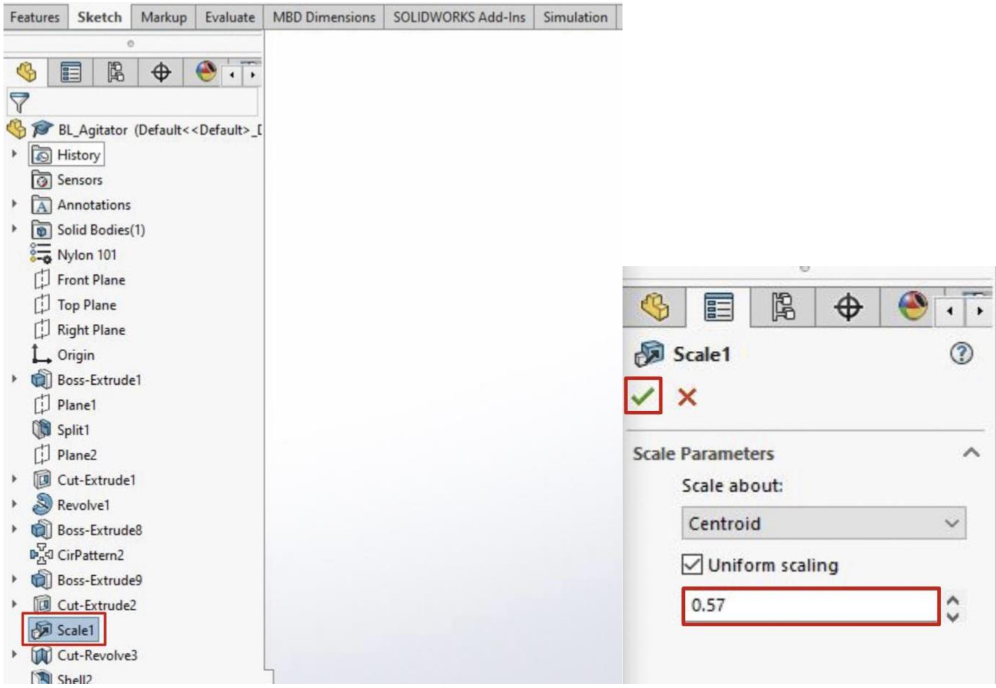


Figure K1. Scaling directions from step 4.

5. **Save As.** Save as a new file with a new name to differentiate this from the original file.

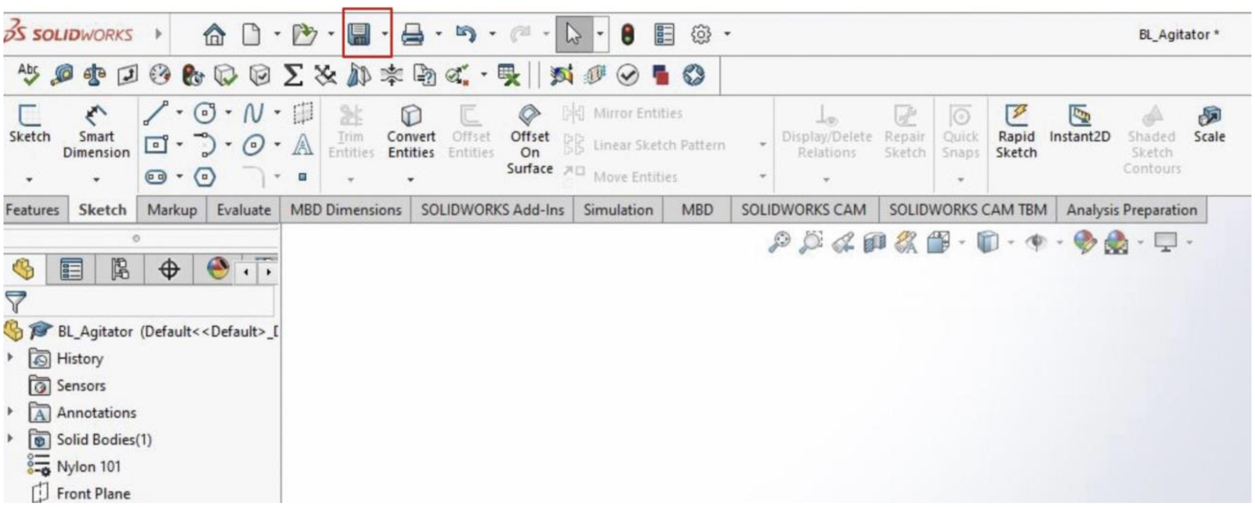


Figure K2. Location of save button for step 5.

Appendix L How to Scale Agitator Mount

This manual serves as documentation for how to adjust the scale of the agitator mount for the Bitter Leaf Washer appliance. It is necessary to adjust the diameter of the mount so it can be easily centered in various sized containers and so leaves do not get trapped underneath the agitator. Only the diameter of the mounts base is altered in this scaling as the pin size is constant in any scaled agitator. The standard agitator mount file is set up for a 1 gallon bucket.

L.1 Steps

1. **Determine the required mount diameter.** Measure the inside diameter of your container to find the necessary diameter in inches. You want the mount to be just slightly smaller than this for an easy fit, so be conservative with the measurement.

2. **Open the SolidWorks file.** Open BL_Mount SolidWorks part file.

3. **Open the base sketch file.** Navigate to the feature manager design tree on the left side of the screen. Click the drop down arrow next to "Boss-Extrude1". Next, right click on "Sketch 1" and select the "edit sketch" option.

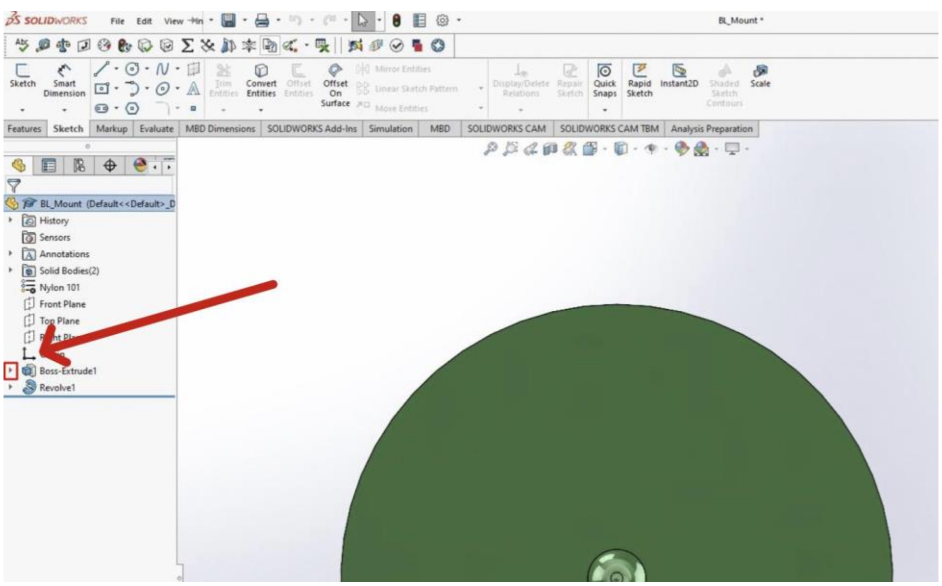


Figure L1. Drop down arrow next to "Boss-Extrude 1".

Figure L2. "Sketch 1" location.

4. **Change the base radius to the desired size.** Click on the circle. Options will appear on the left side of the screen. Among these is the value of the radius which is currently set to 3.125 inches. Change this to your desired radius (half of the measured diameter). Once the desired value has been inserted, click the green check mark.

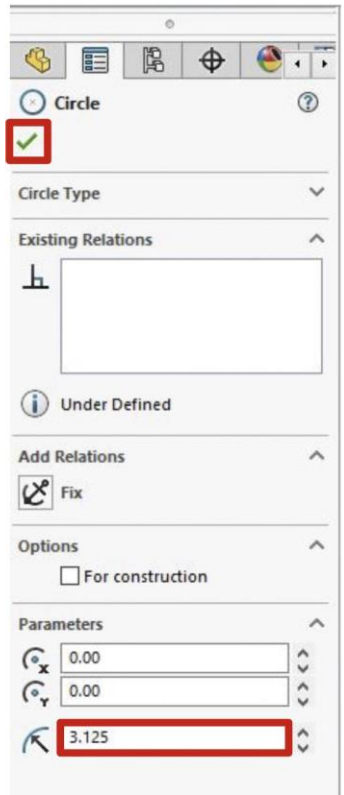


Figure L3. Radius value location and green check mark for step 4.

5. **Save As.** Save as a new file with a new name to differentiate this from the original file.

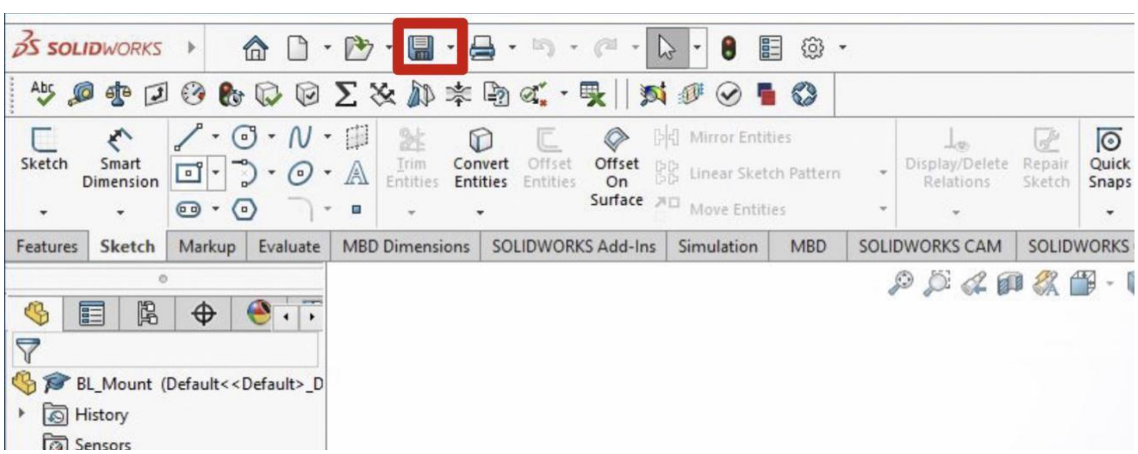


Figure L4. Save location for step 5.

Appendix M 3D Printing Manual

This manual serves as a guide for the 3D printing process. It is necessary that the parts are properly configured to be printed. Using this guide, one should be able to configure all the parts with the proper arrangements so that the devices may be printed and then assembled using another manual.

M.1 Steps

1. **Open the necessary SolidWorks files.** Open all of the necessary SolidWorks part files that you would like to print.

2. **Convert the SolidWorks part files to STL.** In order to print these files, they must first be converted to STL files. This is done by navigating to "Save As", then scrolling down through the file options and selecting STL. Repeat this for each file.

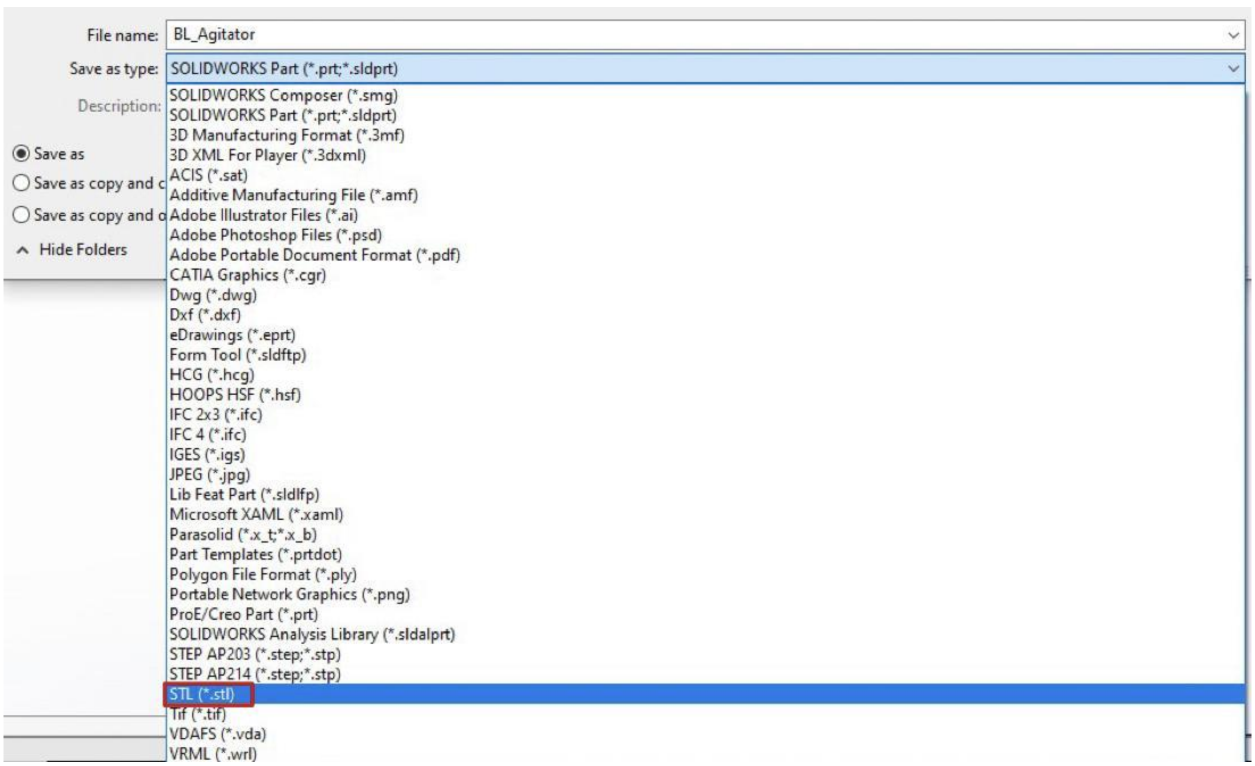


Figure M1. Saving SolidWorks part as an STL.

3. **Setup the part for printing.** These STL files can now be imported into a slicing software such as Cura. This software allows you to place the parts on the print bed and select options for the printing process. Repeat this process for each part you would like to print. If your printing bed is large enough, multiple parts can be printed simultaneously.

    a. **Open the STL file in slicing software.** Open Cura or any similar slicing software and import the agitator STL file [File > Open Files > *FILE NAME*].

    b. **Orientation and settings.** Orient the part so its base is flat on the bed. Next, select the appropriate settings. For our parts, we typically used a layer height of 0.2, and 20% infill. Support is not necessary for most parts but should be used for the crank handle for the washer appliance as it contains an overhanging edge.

    c. **Slice.** Slice the file using the 'Slice' button at the bottom right corner of the screen. Next, save the file to a USB stick.

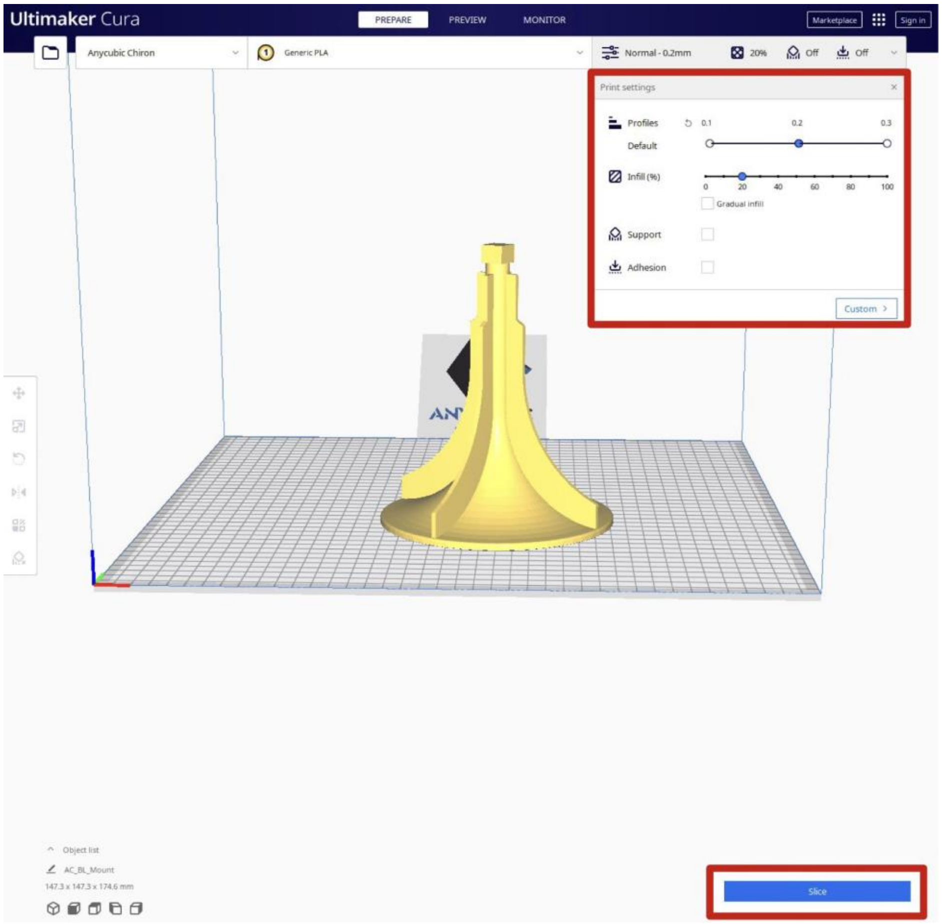


Figure M2. Print settings and slice button.

4. **Print.** Plug the USB into the 3D printer then find the file you would like to print on the screen. Select the file and hit print to start the process.

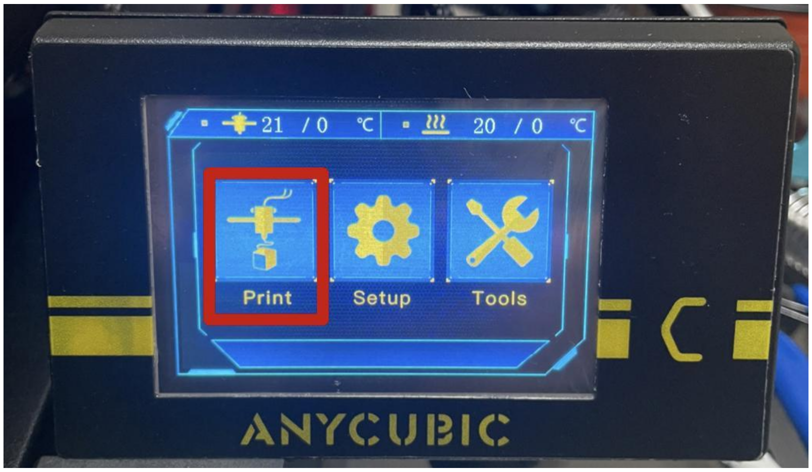


Figure M3. 3D printer screen, 'Print' option.

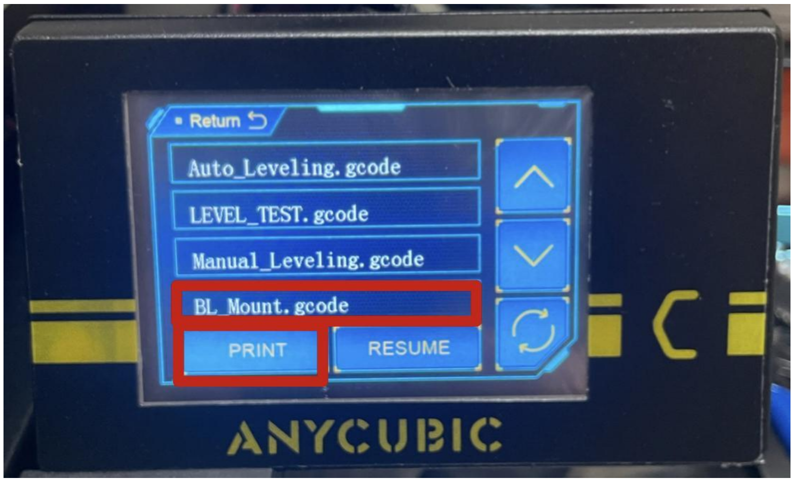


Figure M4. 3D printer screen, file selection and 'Print' button.

Appendix N Eru Leaf Shredder User Manual

The eru leaf shredder is designed to decrease the amount of time required to slice eru leaf. For best results, use this appliance with uncooked, unsoaked leaves.

The appliance parts are provided in the figure below.

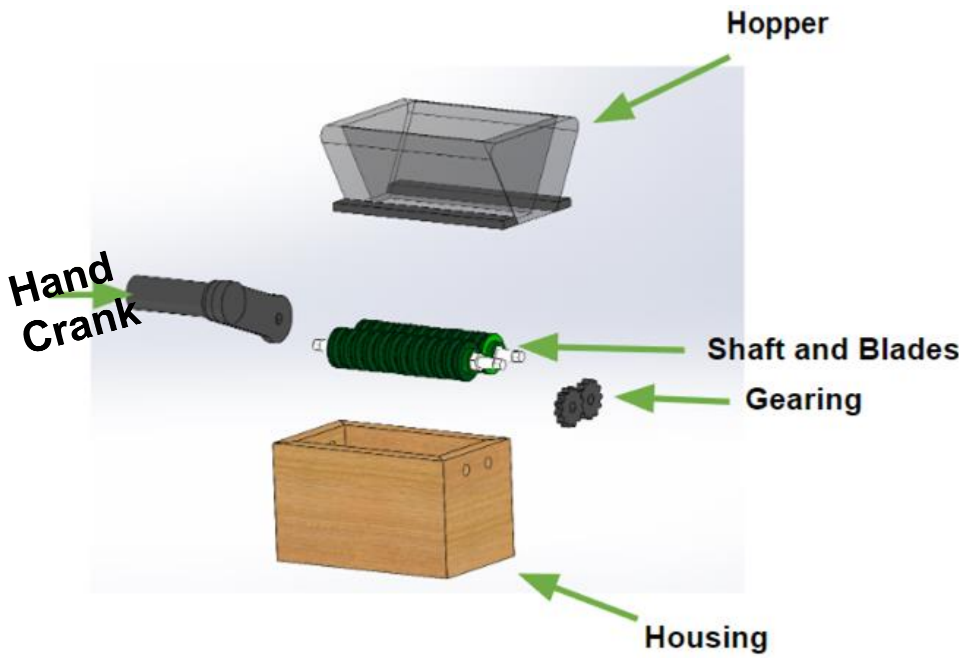


Figure N1. Eru leaf shredder exploded view.

N.1 Steps

1. **Position the shredder.** The shredded leaves will fall out of the bottom of the appliance. To best position the shredder for operation, either place it on a flat surface or over a bowl. If you choose to use the device on a flat surface you may need to periodically lift the appliance and push the sliced leaf into a bowl.

2. **Insert leaves into the hopper.** Insert leaves into the hopper at the top of the shredder. Never put your hands inside the hopper.

3. **Spin the hand crank.** To operate the device, spin the hand crank in a continuous motion. The leaves will be drawn through the spinning blades and be sliced. Insert additional leaves into the hopper as needed.

Appendix O Bitter Leaf Washer User Manual

The bitter leaf washer is designed to decrease the amount of time required to remove bitterness from bitter leaf using room temperature water and limestone. It is recommended to wash in 3-5 minute intervals until the desired bitterness is acquired.

The appliance parts are provided in the figure below.

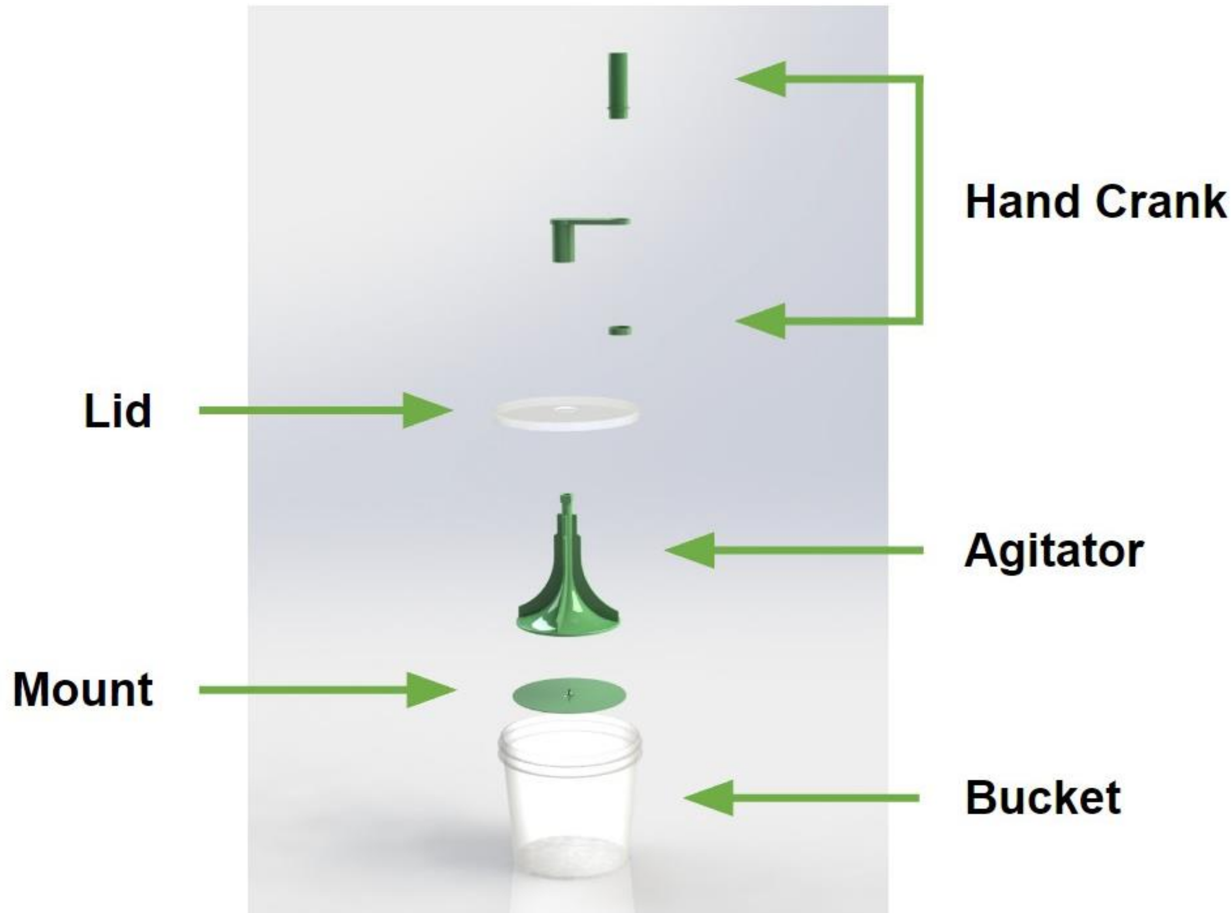


Figure O1. Bitter leaf washer exploded view assembly.

O.1 Steps

1. **Insert the agitator.** Insert the agitator into the bucket and on top of the mount. The hole on the bottom of the agitator should line up with the pin of the mount to allow rotation.

Figure O2. Agitator on top of mount inside bucket.

2. **Insert bitter leaf, water, and limestone.** Insert the bitter leaf directly into the container. For every 2 cups of bitter leaf, insert about ¼ gallon of water. Finally, insert limestone. We recommend about ½ oz per 2 cups of bitter leaf but this is dependent on preference.

3. **Attach the lid and crank handle.** Attach the lid to the top of the bucket then insert the crank handle connector through the hole in the lid and connect it to the top of the agitator. The handle will line up and slot down onto the agitator for a good connection.

4. **Spin the hand crank.** To operate the device, spin the hand crank in a continuous motion. Do this in 3-5 minute intervals and check the bitterness level until the desired taste is achieved. To fully remove bitterness, this process will take about 25 minutes.

Figure O3. Bitter leaf washer.

Appendix P Senior Design Conference Slides

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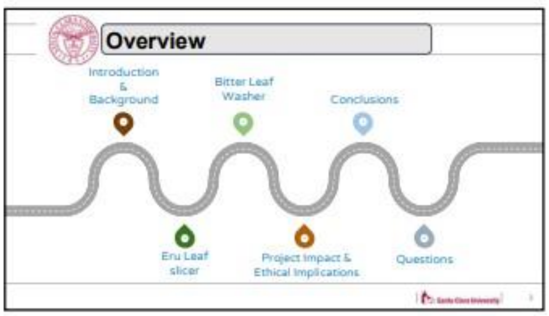

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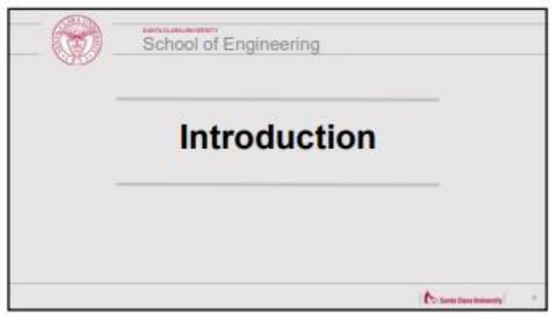

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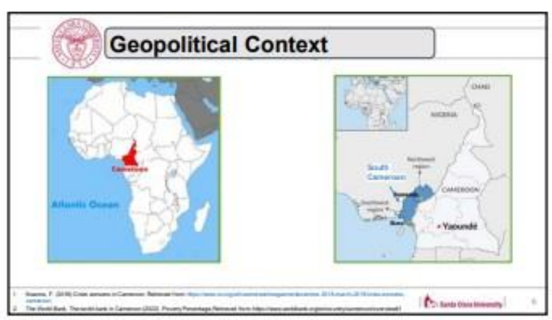

6


Leaf Uses & Importance
Eru Leaf
Bitter Leaf

7


Current Methods - Eru Leaf
Eru leaf sliced using a knife
1. Bundle
2. Cut
3. Cook

8


Current Methods - Bitter Leaf
Bitter leaf washed by hand
1. Soaked in water
2. Scrubbed with hands
3. Repeat multiple times
4. Limestone (optional/regional)

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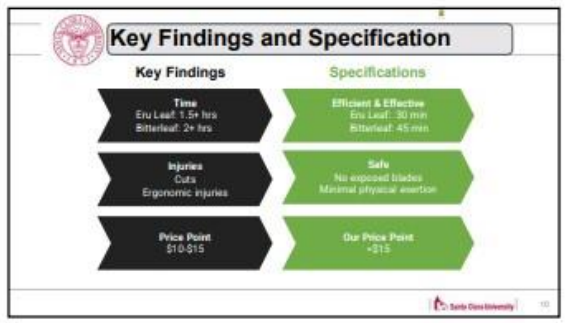
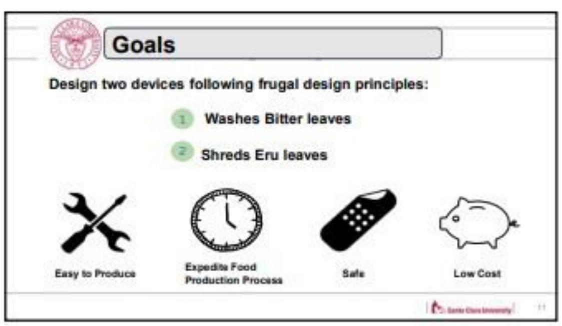

Key Findings and Specification
Key Findings
Specifications
Time
Eru Leaf: 1.5+ hrs
Bitterleaf: 2+ hrs
Efficient & Effective
Eru Leaf: 30 min
Bitterleaf: 45 min
Injuries
Cuts
Ergonomic injuries
Safe
No exposed blades
Minimal physical exertion
Price Point
$10-$15
Our Price Point

10


Goals
Design two devices following frugal design principles:
1 Washes Bitter leaves
2 Shreds Eru leaves
Easy to Produce
Expedite Food Production Process
Safe
Low Cost

11


Systems Overview
Eru Leaf Slicer
Bitter Leaf Washer

12

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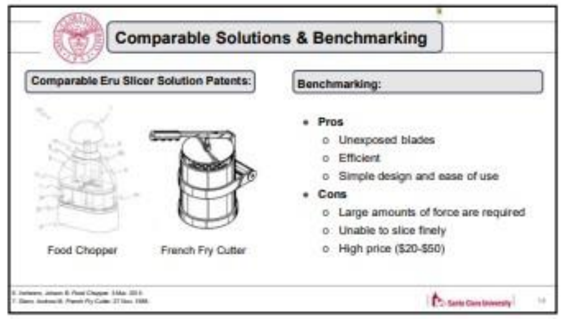

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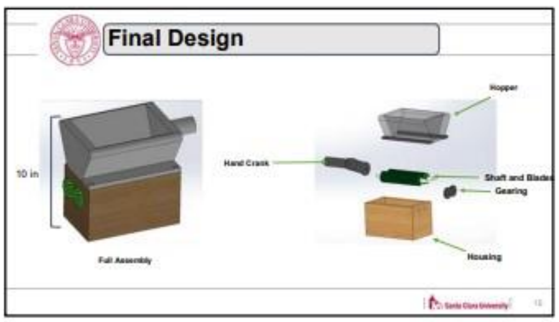

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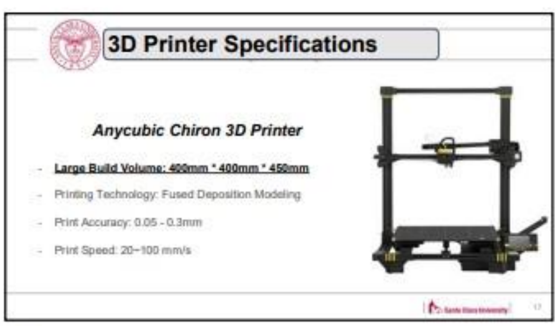

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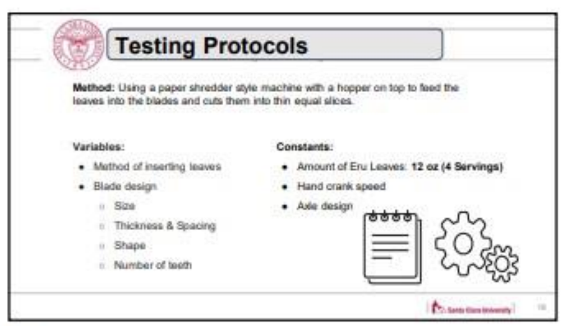

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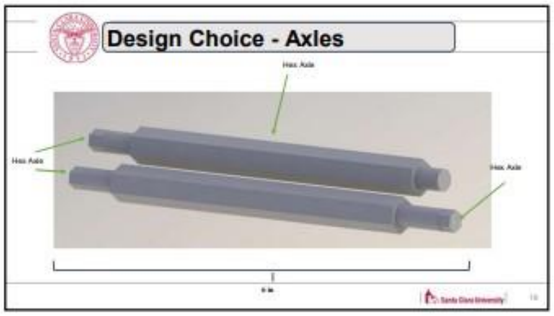

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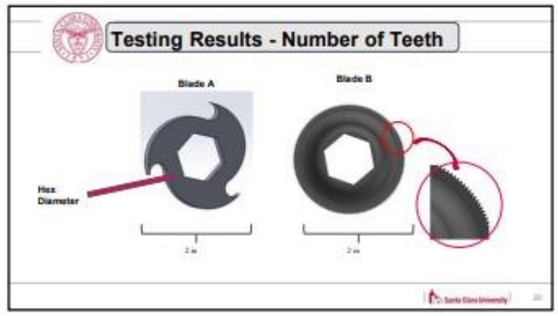

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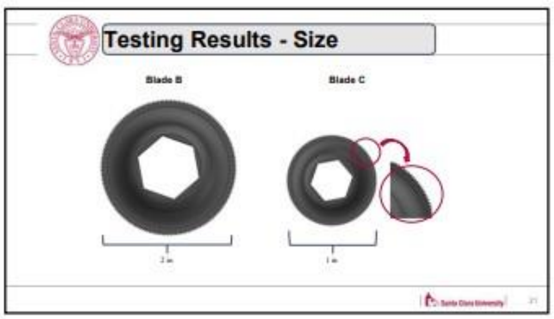

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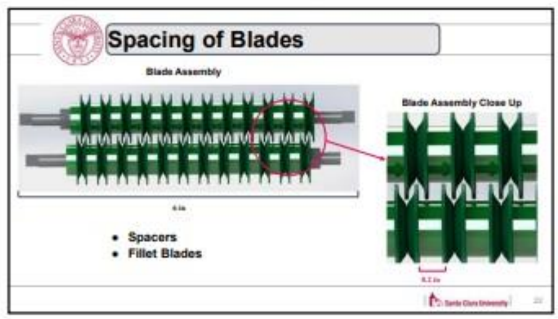

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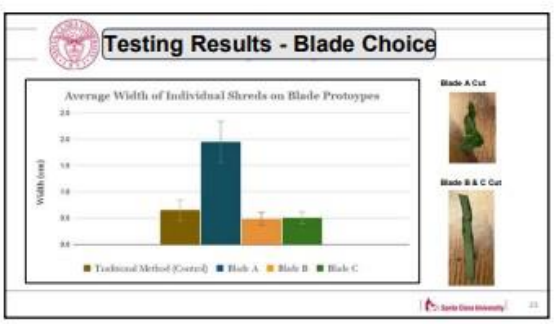

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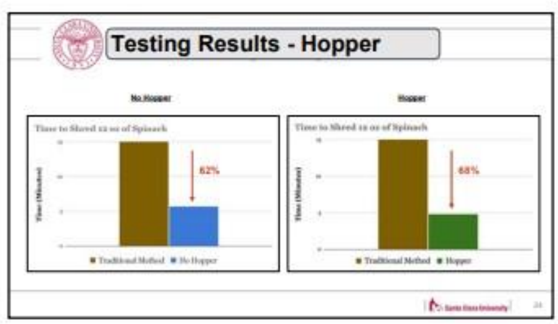

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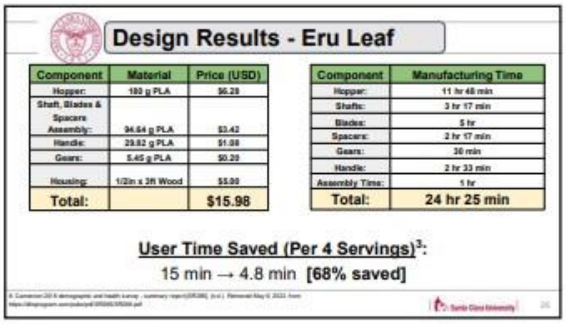

Component	Material	Price (USD)
Hopper:	180 g PLA	$6.28
Shaft, Blades & Spacers Assembly:	94.64 g PLA	$3.42
Handle:	29.82 g PLA	$1.08
Gears:	5.45 g PLA	$0.20
Housing:	1/2in x 3ft Wood	$5.00
Total:		$15.98

Component	Manufacturing Time
Hopper:	11 hr 48 min
Shafts:	3 hr 17 min
Blades:	5 hr
Spacers:	2 hr 17 min
Gears:	30 min
Handle:	2 hr 33 min
Assembly Time:	1 hr
Total:	24 hr 25 min

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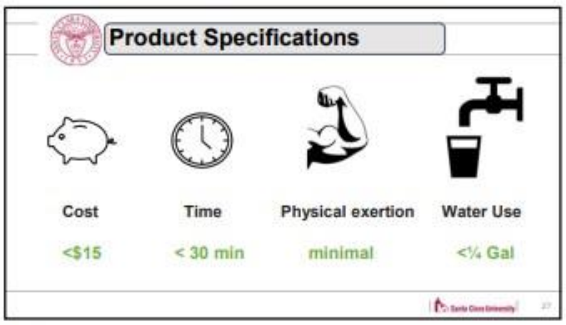

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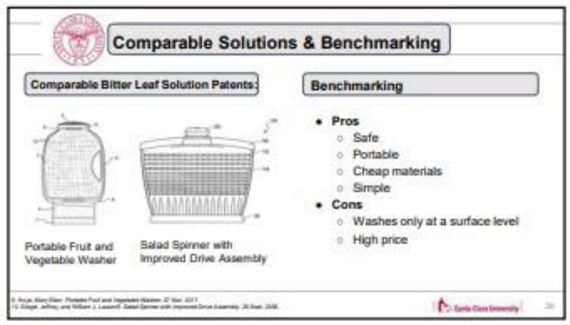

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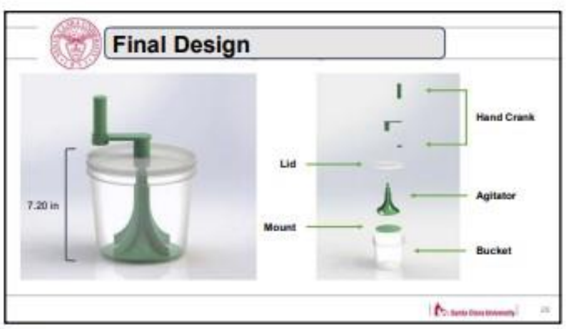

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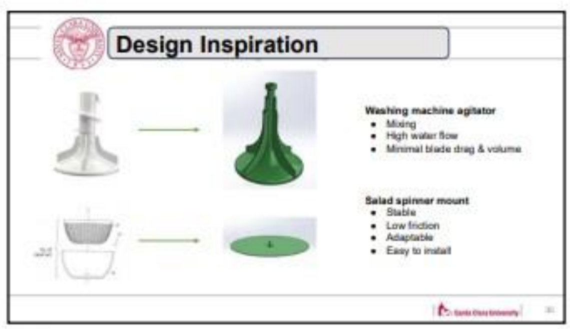

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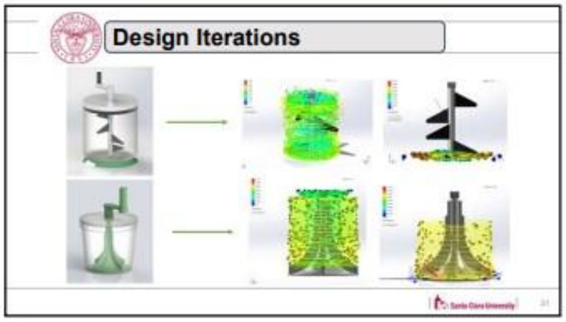

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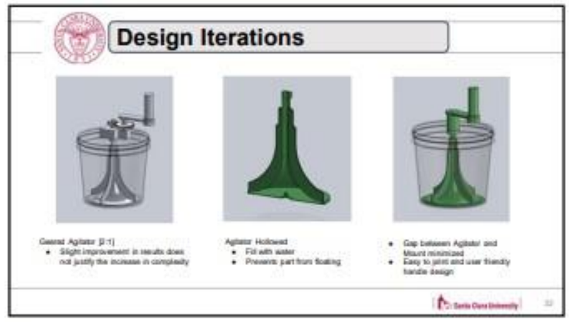

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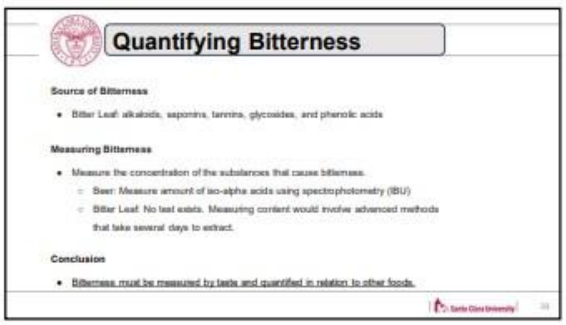

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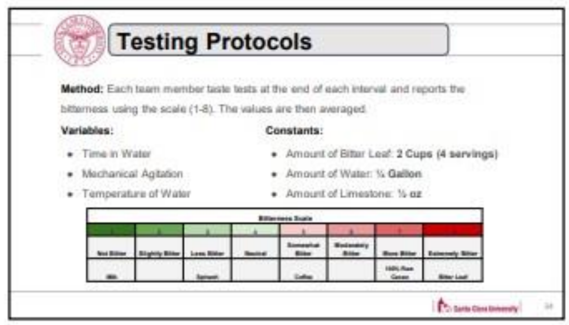

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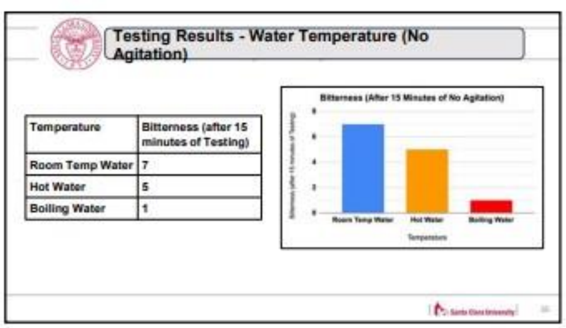

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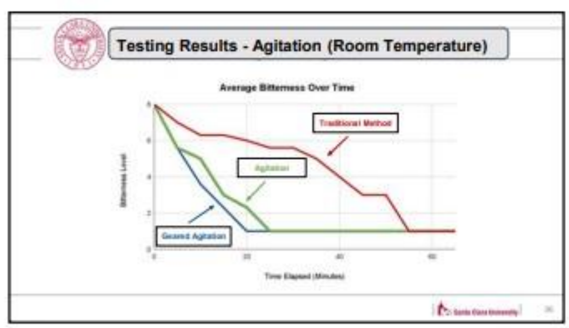

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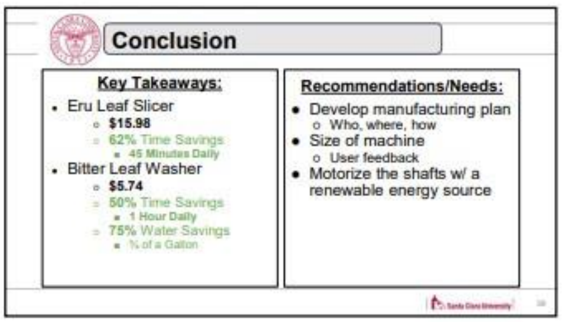

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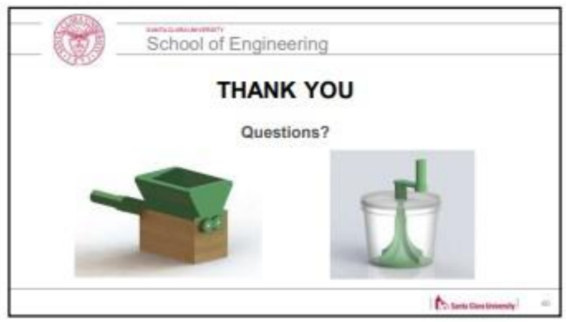

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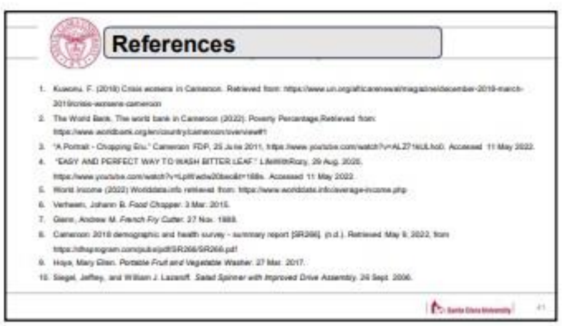

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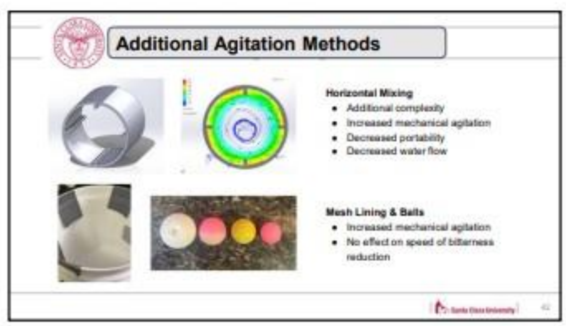

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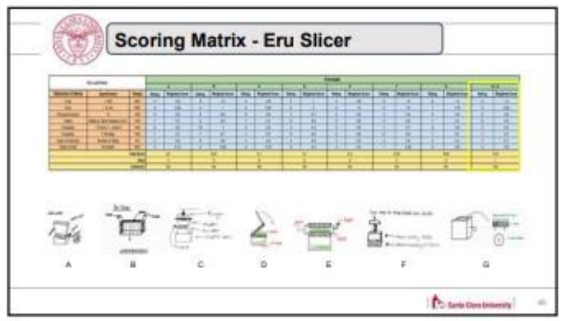

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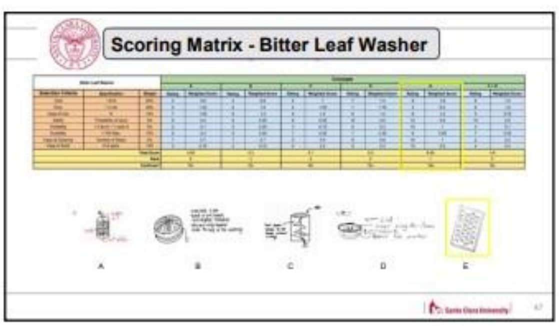

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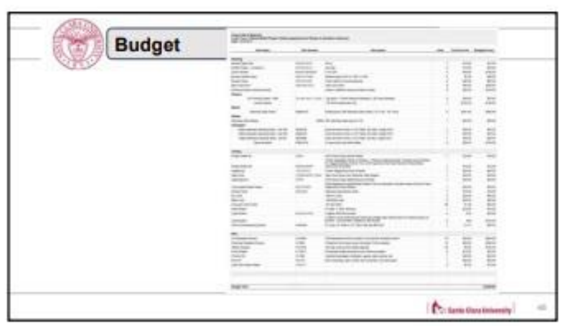

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